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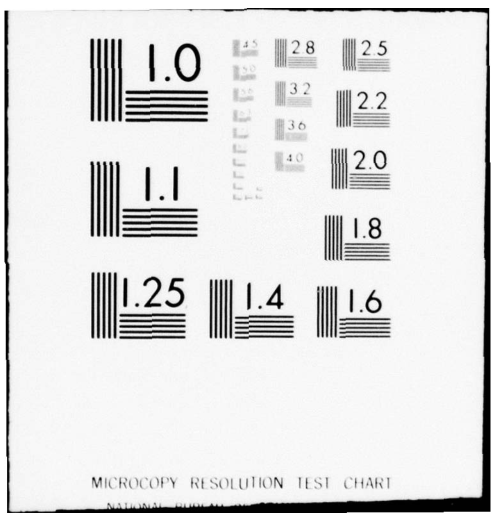
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TOTAL ENVIRONMENT SURVIVABILITY METHODOLOGY

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This report has been reviewed by the Information Office (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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This report documents the results of an analytical study to develop an architecture for a Total Environment Survivability (TES) methodology to provide a capability to evaluate the relative importance of: (1) threats on technologies and (2) technologies on air flight vehicle non-nuclear survivability in the total environemnt. This methodology couples mission effectiveness and life cycle cost analysis techniques to yield a final measure of merit (MOM) or payoff for each technology evaluated. Three candidate methodologies are described which (over)

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were studied and compared to arrive at the final selected approach. The selected methodology is described in detail along with a qualitative assessment of the methodology using a candidate technology and threat problem. The report also documents the development plan for the implementation of the methodology.

PREFACE

The work reported herein was undertaken by Calspan Corporation, Buffalo, New York, under Contract F33615-77-C-1212, Project 24020304, for the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The Air Force Technical Monitor for the project was Mr. E. Roberts (AFFDL/FER). Calspan Project Engineer was Mr. C.J. Krebs.

Principal contributions to the study were made by Mr. H.G. Reif and Mr. W.F.H. Ring with supporting data provided by Mr. J. Ball and Mr. A.R. Kidder. Recognition is also given to Mr. C. Mayrand (AFFDL/FER) and Mr. A. Mayer (AFFDL/FEE) for their constructive critique of the methodology during its development.

The work reported herein was performed during the period from October 1977 through March 1978. The report has been assigned Calspan Report No. 6200-X-2.

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LIST OF SYMBOLS

RF	Radio frequency
IR	Infrared
E/O	Electro-Optical
P_{AB}	Probability of attrition, baseline
P_{SB}	Probability of survival, baseline
$P_{A(MOD)}$	Probability of attrition modified by technology improvement
$P_{S(MOD)}$	Probability of survival modified by technology improvement
Σ, Π	Sum and product combinations
$C_{B(NCP)}$	Baseline costs (noncombat and peacetime)
$C_{M(NCP)}$	Modified (new technology) costs (noncombat and peacetime)
$C_{B(C)}$	Baseline costs (combat)
$C_{M(C)}$	Modified (new technology) costs (combat)
C_{TR}	Cost of reduced treat
C_{TP}	Cost of technology program
C_T	Initial threat cost
PVC	Primary vehicle characteristic
PAF	Projected Air Force
TAF	Technology improved Air Force
LCC	Peacetime life cost costs
Δ	Change in
Δ C/E	Change in cost-effectiveness
V_i	Value of ith alternative

I_m	Importance of objective m
C_{mi}	Contribution of alternative i to objective m
W_j	Weighting function
$U_{(a_{ij})}$	Utility function
r_K	Face cost
u_{jk}	Utility coefficients
I_T	Threat index
$P_{(E/S)}$	Engagement probability per sortie
C_E	Average cost per engagement
$N_{F/I}$	Number of systems or equipments in the fleet or inventory
C_S	Cost of system
TPC	Technical performance characteristics
C_{OT}	Cost of extant technology
C_{NT}	Cost of new technology
NC_{NT}	Net cost of new technology
N_E	Reported number of birdstrike incidents in time t
N_H	Number of flying hours per aircraft per year
T_A	Average flight hours per sortie
t	Timeframe of interest (years)
$I_{T(OT)}$	Threat index extant (old) technology
$I_{T(NT)}$	Threat index new technology

SECTION I
INTRODUCTION

This report documents the work performed by Calspan Corporation under a six-month program to develop a Total Environment Survivability (TES) Methodology. For the purpose of this program, total environment survivability is defined as:

> The capability of an air flight vehicle to avoid and/or withstand a non-nuclear man-made hostile, natural, or induced environment associated with the total spectrum of operational conditions <u>without sustaining an impairment of its ability to accomplish its designated mission.</u>

Based upon this definition, anything (non-nuclear) which impairs the ability of an air flight vehicle to accomplish its designated mission can be considered to constitute a threat to the vehicle's survivability.

The program overall is intended to outline a viable procedure for evaluating the relative importance of threats on technologies and technologies on air-flight vehicle survivability in operational environments consisting of both <u>wartime and peacetime threats.</u> The derived TES methodology is to include the influence of mission effectiveness and life cycle costs in arriving at measure of merit for each of the multitude of technology areas and programs of interest to the Air Force.

Conceptually, the measures of merit derived from exercising the TES methodology would be used by Air Force planners to rank candidate technology programs (e.g., at the Laboratory level) for potential funding support, to delineate pay-off benefits for the initiation of new and/or continued pursuit of existing technology areas and most certainly, to provide data for establishing defensible decisions for selection of specific technologies for funding support from a host of possible candidates. Under the current program, the TES methodology does not attempt to define procedures for establishing the relative degree of funding support that should be applied to technology areas

examined using the methodology. Neither does the program attempt to establish risk (or success) probabilities for the various technologies given that specific programs were formulated and hypothetically funded for each technology candidate. The above restrictions represent boundary conditions for the current methodology development effort and in our view represent a limit that a methodology for research planning cannot reasonably exceed.

To achieve the stated objectives, the program was divided into four specific tasks as listed below.

- Task 1 Development of candidate methodologies from which a final selection would be made;
- Task 2 Identification of model/module requirements to support implementation of the selected methodology;
- Task 3 Perform a qualitative assessment of the selected methodology using a candidate technology and threat problem prescribed by the program's technical monitor;
- Task 4 Development of a follow-on task plan for implementation of the methodology.

Section 2 of the report summarizes the program scope, objectives, and limitations. In addition, the section presents an overview of the recommended methodology along with indications as to its strengths and weaknesses. Section 3 outlines the rationale and functional characteristics of various methodology approaches examined during the program from which the final version, detailed in Section 4, evolved. Module requirements for the recommended TES methodology are detailed in Section 4, while Section 5 presents a qualitative assessment of the methodology to alleviate the candidate birdstrike (threat) problem associated with the F-111 wind screen. Program recommendations for implementation of the methodology are presented in Section 6.

SECTION II
PROGRAM SUMMARY

2.1 INTRODUCTION

The objective of the Total Environmental Survivability (TES) methodology program is to provide Air Force planners with the capability to evaluate the relative importance of (1) threats on technologies, and (2) technologies on air flight vehicle nonnuclear survivability in the total environment. This capability is to be associated with mission effectiveness and life cycle cost analyses to provide a ranking of the relative payoffs of the alternative technologies.

To achieve the stated objective, the scope of the TES methodology must be sufficiently broad to insure that a comprehensive assessment of Air Force R&D technologies and planning goals is achieved. In this regard, numerous (Reference 1) attempts have been made in the past to develop useful methodologies for R&D and technology planning. These have generally provided unsatisfactory results for a variety of reasons, some of which include:

- Difficulties in quantifying R&D and technology goals
- Attempt to include all factors affecting R&D technology planning, many of which can only be superficially defined
- Difficulties in establishing "acceptable" weighting factors representing the relative importance of each of a large number of diverse technology areas
- Complexity of evaluation methodologies
- Extensive amount of required input data
- Questionable validity of input data even when provided by "experts"
- Low confidence or non-acceptance of methodology results at various levels within the Air Force hierarchy
- High implementation and operating cost.

The deficiencies and limitations of previously developed R&D planning methodologies are discussed in detail in two Rand Reports (References 2 and 3). The shortcomings of these earlier attempts can be attributed largely to the failure to set limits for the scope of the methodology at the outset. The problem then becomes one of establishing limits which are sufficiently broad to accept and evaluate advanced concepts and technologies which may differ in significant attributes from current technologies and at the same time impose restrictions based on definability and measurability.

The limits applied in the TES methodology derive from the definitions of technology, threat and air-flight vehicle survivability. The definitions are:

Technology: A bank of knowledge derived from scientific endeavor applied in a useful manner. For example, information processing which belongs to the class of engineering sciences, becomes a technology area when applied to reconnaissance and airborne surveillance problems. Directed (supporting) research conducted under AF 6.1 and 6.2 funding is included within the definition of a technology, while non-directed (basic) research is not.

Threat: Anything (non-nuclear) which impairs the ability of an air-flight vehicle to accomplish its designated mission regardless of origin (i.e., man-made, natural, or induced). For example; man-made threats include weapon system effects resulting in blast pressure, fragments and projectiles; natural threats include bird impacts, lightning strikes, hail, etc; and induced threats include abnormal pressures, temperatures, g-forces, etc.

Survivability: The capability of a flight vehicle to avoid and/or withstand a non-nuclear man-made hostile, natural, or

induced environment associated with the total spectrum of operational conditions without sustaining an impairment of its ability to accomplish its designated mission.

Technology, as defined above, is directed towards a specified objective(s) which can be related to a particular item of equipment, a class of systems and their operation, or to flight vehicles in general. Moreover, only technology areas which apply to air-flight vehicles and their operations are relevant within the limits of this study program. However, this is not necessarily a constraint on the methodology in general. This degree of specificity allows for the description of technology areas in terms of technical characteristics and flight vehicle performance parameters where the latter are impacted by the technologies. In turn, this information provides requisite inputs for survivability and mission effectiveness analyses. Only threats which affect the survivability, mission effectiveness, and economic aspects of air-flight vehicles fall within the scope of this program.

While the above establishes general limits for the scope of the program, the diversity of technologies, threats, and missions which relate to air-flight vehicles still represent a formidable number of threat-technology combinations that will require examination using the methodology. Further, the evolutionary nature of technologies, their intrinsic characteristics and gross differences, and particular state of development at the point in time when evaluation and ranking are desired, suggests that the methodology will in large measure deal with a spectrum of candidate technologies for which few analytic, computer, or other simulation tools will exist or be adaptable for use in the evaluation/ranking process for the entire spectrum.

The development of appropriate technology models or simulations as part of the TES methodology is considered impractical. This is based on; (1) the probable number required, (2) their specialized characteristics and limited scope of application, (3) development cost implications, and (4) timely availability. The methodology therefore is primarily procedural in nature; that is, emphasis is directed to providing a team of analysts with an ordered sequence

of steps for establishing threat ranking, potential worth of candidate technologies to alleviate identified threat problems and cost-benefit decisions supportive for ranking of the technologies.

The methodology proper, requires the identification and ordering of threats according to their relative importance or influence on air vehicle operations; selecting and evaluating technologies which address the threats, and deriving of a priority listing of the technologies corresponding to the threat priorities. In addition, the methodology must accept for evaluation and ranking, technologies for which threats or air vehicle problems are not identified as principal drivers; technologies that may provide, for example, improvements in air vehicle performance, new operational capabilities or reductions in economic areas which contribute to life cycle costs.

2.2 RECOMMENDED TES APPROACH

Figure 1 illustrates the flow and principal features of the recommended approach. In the figure, initial emphasis is given to the identification and ranking of all threats which affect the operational readiness and use of air-flight vehicles. The threat identification process involves the collection, review, and evaluation of information obtained from Air Force records, data banks, and other sources concerning the types, causes, conditions, severity (material and economic), and frequency of occurrence of operational problems associated with each type and class of air-flight vehicle. The derived "problem statistics" then serve as the basis for both war time and peace time threats identification and ranking.* The statistics also provide essential information for establishing threat-related technology goals and requirements.

The results of the threat identification/ranking process provide the Air Force with comprehensive listings of air-flight vehicle threat problems for which technology improvements are desired. In addition, the results form

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*The reasoning for development of separate war time and peace time threat listings is detailed in Section 4.

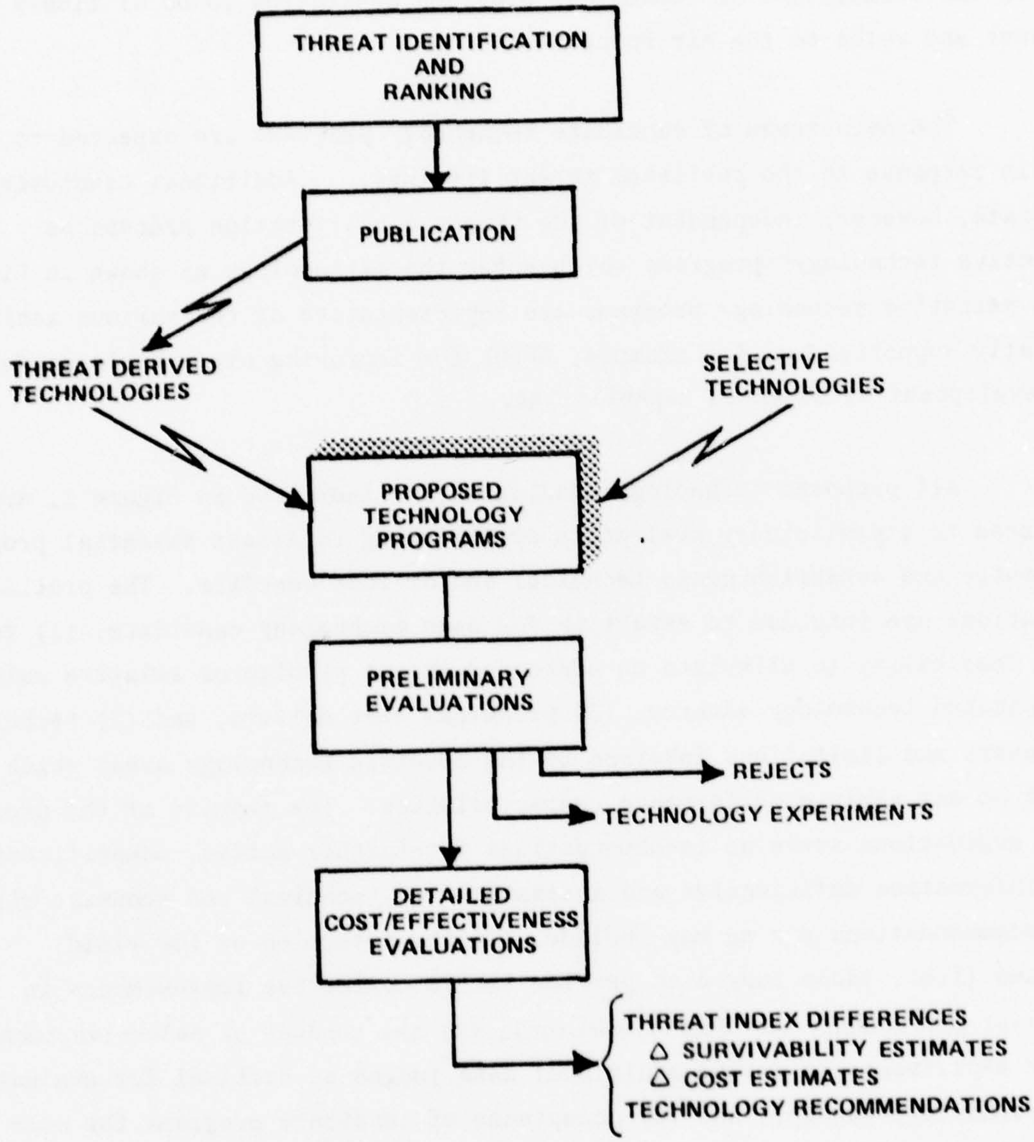

Figure 1 TES Methodology Overview

the basis for soliciting from both government and industry sources technology inputs specifically responsive to the identified threat problems. Publication of the threat listings and related information, therefore, represents the first step in the formulation of technology programs considered to be of timely interest and value to the Air Force.

The mainstream of candidate technology programs are expected to originate in response to the published threat listings.* Additional candidates can originate, however, independent of the threat classification process as "selective technology" programs which enter the methodology as shown in Figure 1. These selective technology programs are representative of the various activities typically supported by, for example, AFFDL for improving air vehicle performance and development of advanced capabilities.

All proposed technology candidates, as indicated in Figure 1, are subjected to a preliminary evaluation or screening to assess essential program attributes and establish gross technical and/or cost benefits. The preliminary evaluations are intended to establish for each technology candidate, (1) technical feasibility to alleviate an addressed threat problem or relative value of an indicated technology advance, (2) principal cost drivers, and (3) technical parameters and limitations inherent to the specific technology areas which impact on air vehicle performance characteristics. The results of the preliminary evaluations serve as recommendations for further action, identification of data/information deficiencies and assessments of technical and economic risks. The recommendations per se may include, (1) the rejection of low yield programs (i.e., those judged to provide little collective improvements in technical performance and cost reduction), (2) the conduct of selective technology experiments to derive additional data judged as critical for evaluation of a technology concept, and (3) acceptance of candidate programs for more detailed examination.

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*Publication of revised threat listings would be conducted on an annual basis.

Detailed examination of technology candidates following initial screening, involves evaluating their influences on air vehicle survivability, mission effectiveness and life cycle costs within an operational frame of reference. This requires that the technical characteristics of the technologies be identified with and quantified in terms of the various performance, structural, signature (i.e., RF, IR, E/O) or other relevant parameters of air-flight vehicles. Technologies, by their nature, however, are generally ill-defined in these areas; particularly for technologies at the basic Research (6.1) and Exploratory Development (6.2) levels.

The survivability and mission effectiveness evaluations, therefore, are contingent upon acceptable correlation and projection of candidate technologies in terms of the performance characteristics of air-flight vehicles. Cases will exist where such correlation/projections are too speculative to justify the detailed evaluations particularly in the area of mission effectiveness.

Separate evaluations would be conducted for both technology improved and unimproved air-flight vehicles with the results of each combined in tradeoff studies. The tradeoff studies assess the advantages and limitations of the technologies on air vehicle operations and determine the relative ranking of alternative technologies with respect to minimum performance and maximum performance - maximum penalty criteria. Other studies also aid in selecting levels of investment which either maximize benefit/cost ratios or maximize the increase in survivability within selected performance, effectiveness, and cost criteria.

2.3 SUMMARY OF IMPLEMENTATION PLAN

The current program had as its principal objective, the development and qualitative assessment of a system architecture for the identification, evaluation and ranking of threats and related candidate technology programs. The selected approach has been noted to be primarily procedural in nature with reduced emphasis on the extensive use of computer models and/or simulations. The procedural aspects of the methodology emphasize the application of an

ordered sequence of steps (or events) by which a team of analysts can establish threat rankings, the potential worth of candidate technologies and formulation of cost-benefit decisions for ranking of the technologies.

The organization of the TES methodology is such that it permits the derivation of specific (and usable) outputs either before being fully implemented or without requiring that the methodology always be exercised in its totality.

For example, Figure 1 indicates that major information and decision outputs would be available (1) with the publication of the identification and ranking of threats, (2) following the preliminary evaluation of proposed technology programs, and (3) following the detailed cost/effectiveness evaluations. The recommended approach for implementation of the methodology, therefore, is that of a sequential three-phase program to develop the organizational and analysis procedures, data requirements and computer models (as appropriate for the cost/effectiveness evaluations) for use under each of the major steps in their order of occurrence as shown in Figure 1.

Phase 1 of the implementation program would develop comprehensive listings of noncombat threats,* related threat statistics and definition of new technology goals for publication approximately twelve months after program initiation. Phase 2 of approximately four months duration, involves a consulting type effort to assist AFFDL in developing the procedures, and output requirements for conduct of the preliminary evaluation or screening of candidate technology programs. Computer models are not envisioned for development and use under the Phase 2 effort. Phase 3 concentrates on development of the tradeoff analyses and computer models envisioned for conduct of the effectiveness, cost and cost/effectiveness evaluations.

The Phase 3 effort develops the analyses and computer models in two stages over a twelve month time period; the first stage establishing the analysis procedures, preliminary model requirements and algorithms to a point for

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*Combat threat identification, etc. would be conducted concurrent with Phase 3 to optimize the development of survivability and mission models.

exercising against a number of identified technology candidates, with demonstration completed under the second stage. Full implementation of the methodology could be realized approximately twenty-four months after Phase 1 start although initial outputs from the threat identification and ranking portion of the methodology would be available twelve months after Phase 1 initiation. It should be recognized that exercising of the methodology over an extended time period will undoubtedly reveal unanticipated problems and selective areas where refinements and updating are warranted. This type activity is beyond the present planning effort and therefore not explicitly included as a portion of the recommended follow-on program. Full implementation of the methodology is estimated at a $340K funding level. Specifics of the current implementation plan including a time schedule and estimated cost by phase are presented in Section 6.

SECTION III
CANDIDATE TES METHODOLOGIES

3.1 INTRODUCTION

Air Force planners continuously support a wide variety of technology areas in order to maintain and increase our military advantage and capabilities over those of potential adversaries. In one sense, some technology programs are pursued merely to expand fundamental knowledge in scientific disciplines which may, in varying degrees, impact on or be of value in establishing future military requirements while others are pursued to formulate and develop new capabilities which ultimately result in the fielding of advanced weapon systems against which an enemy may have little or no defense. In an alternative sense, some technology programs necessarily are conducted in order to minimize the potential for any enemy to field systems or gain military superiority in technology areas where U.S. expertise would otherwise have been deficient.

While the above represent completely justifiable objectives for supporting selective technology areas, one recognizes that the vast majority of military technology programs are directed toward the improvement of capabilities and reduction of deficiencies for existing and near-term systems against known and projectable threats. Again, one also recognizes that some technology advances when actually implemented and incorporated into avionics systems of aircraft, missiles or RPVs may result in some degradation in system performance, increased acquisition and/or maintenance costs or reduced vehicle survivability, even though the specific goal for incorporation of the technology improvement may have been realized. In summary, recognition must be given to the fact that the known threat environment and its impact on existing and near-term systems directly influences the mainstream of technology requirements and programs and that the prediction of "operational" cost performance benefits attributable to each of a host of candidate technology programs is a necessary requisite if efficient allocation of limited funds is to be achieved.

Any methodology that efficiently derives the indicated operational cost performance benefits represents a significant aid to the decision process for selecting specific technology programs for funding support in any given fiscal year. In this regard, Section 2 listed a number of drawbacks concerning past R&D and technology planning methodologies with the principal observation that their nonacceptance has largely been attributed to a failure to set realistic limits for the scope of the methodologies at their outset. Closely akin to this problem have been attempts to model facets of the planning process which address the subjective and often conflicting and changing directives concerning longer range technology and military planning goals.

For the present program, if the scope of the TES methodology becomes too encompassing, the methodology and results thereof become subject to the same difficulties as those noted above and in Section 2, whereas too narrow a scope is likely to produce results of limited and questionable usefulness. A reasonable compromise may be achieved, however, if one focuses his attention on definable quantities concerning the majority of threat vs. technology problems while simultaneously maintaining an awareness of potential methodology growth requirements in areas that are relevant to the subject in question, but presently too nebulous in scope or content for effective definition and modelling.

In order to define and implement the compromise noted above, three levels of architecture were initially examined for the TES methodology. The first level, described in Section 3.2, represented a straightforward approach to derive changes in vehicle survivability, mission effectiveness and life cycle costs resulting from proposed technology improvements relative to definable baseline conditions. The second level, described in Section 3.3, addressed the broader range of technology requirements which evolve as a direct consequence of the priority ranking of existing or projected future threat situations which then produce candidate technology solutions requiring subsequent evaluation and ranking using survivability and life cycle cost analysis procedures. The third level, outlined in Section 3.4, addressed the fundamental problem involving the optimum allocation of limited resources, as established

by DOD, throughout the totality of the Air Force based on defining and evaluating the marginal utility of the resources to satisfy established AF operational objectives. Each of the methodology approaches are compared in Section 3.5 for advantages and limitations which impact on the recommended approach presented in Section 4.0.

3.2 CANDIDATE METHODOLOGY NO-1

3.2.1 Introduction

Technology efforts, as previously noted, are largely directed toward minimizing existing or projectable threat situations*. Recognition of a threat situation interacting with a given air flight vehicle permits, in varying degree, the specification of critical threat conditions and parameters, severity of the threat and potential impact of the threat on vehicle survivability and mission success. Quantifying the threat situation permits the delineation of technology requirements. To the extent that the requirements can potentially be satisfied, assessments can be derived relating to improvements in vehicle survivability and mission success and life cycle costs. In effect the TES methodology must permit correlation of the influences of:

Threats		
Mission/Mission Requirements		Existing Technologies
Mission Success	on	and Projected
Vehicle Survivability		Future Requirements
Life Cycle Costs		

New or advanced technologies would enter the evaluation process by relating the technology to an appropriate air flight vehicle, its intended mission(s) and the likely threat situations it will encounter.

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* "Threat Situation" here is interpreted as anything that inhibits or degrades an air flight vehicle from achieving its mission in an optimum sense.

Figure 2 presents a schematic flow diagram linking the various factors of concern in developing the candidate TES methodology. In the figure, mission/mission requirements are shown as an initiating point establishing both the type of air vehicle and to a large extent, the systems and subsystems that would be involved in any survivability, mission effectiveness and cost analyses. Threat considerations are shown as impacting on mission requirements and profiles and again, on the selection of specific systems and subsystems to be carried by the airflight vehicle. Specification of the missions, threats, air vehicles and related systems and subsystems provide the basis for developing the analysis/modelling requirements for assessing performance and mission effectiveness. Since technology improvements can influence the performance characteristics of both the air-flight vehicle and its selected subsystems, the effectiveness and cost models must include a capability to perturbate those parameters most closely associated with or attributed to a candidate technology in order to derive the measures of merit for ranking of the Technology improvements.

3.2.2 Methodology Description

Figure 3 shows the application of the planning procedure of Figure 2 to the candidate TES methodology. For Figure 3, the underlying principal of the methodology involves the development of measures of merit that reflect changes (either positive or negative) from the "Status Quo" in mission effectiveness, vehicle survivability, and life cycle cost as a result of specified (or projected) technology improvements. The architecture of the methodology therefore is shown as a dual evaluation process; one evaluation being conducted for base case conditions, the other using parameter changes reflecting selected technology improvements. Results obtained from the two evaluations (i.e.; base case and for the modified parameters conditions) then serve as inputs to derive the desired cost-benefit measures of merit for the candidate technology.

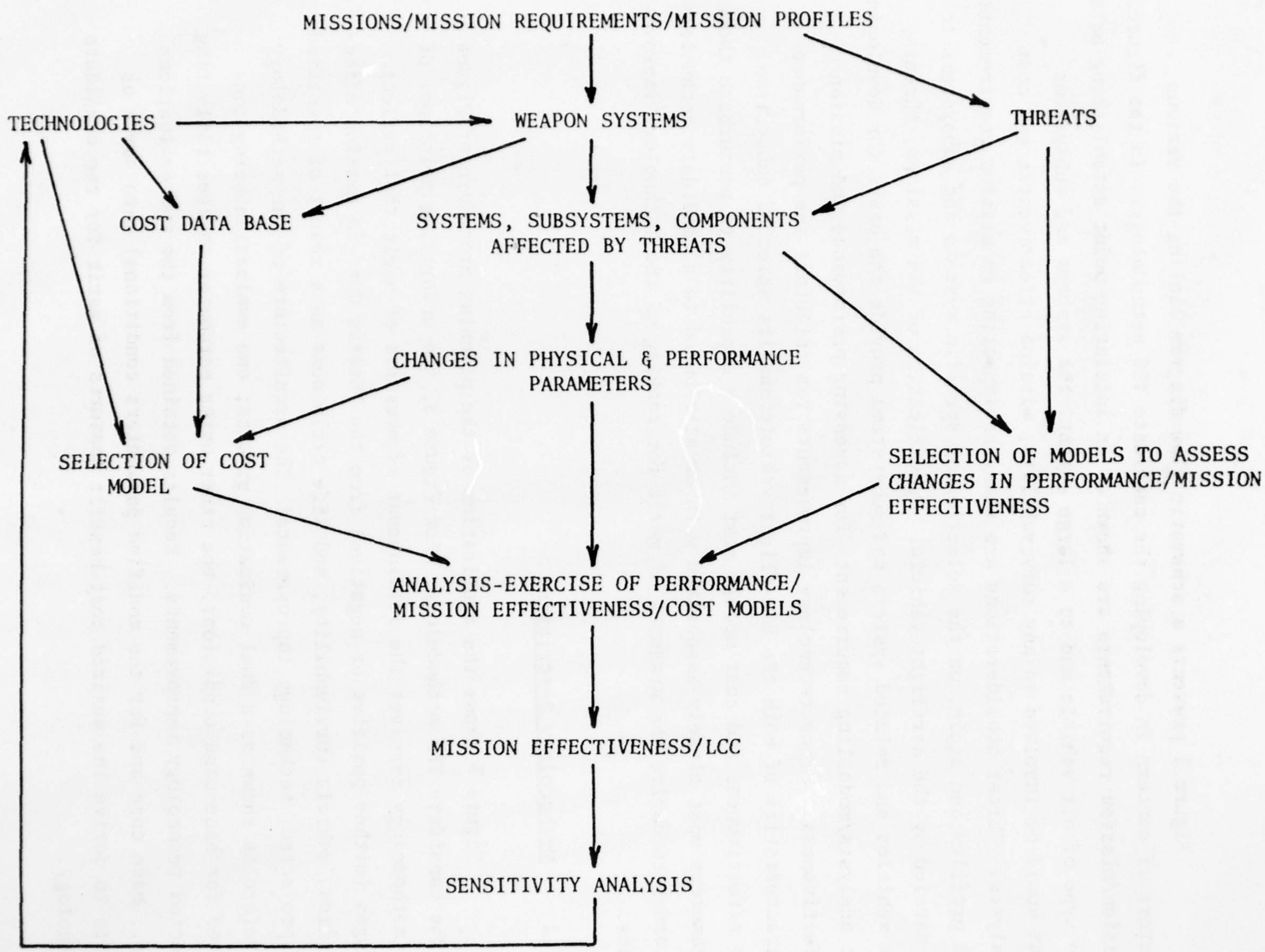


Figure 2 Methodology Planning Diagram

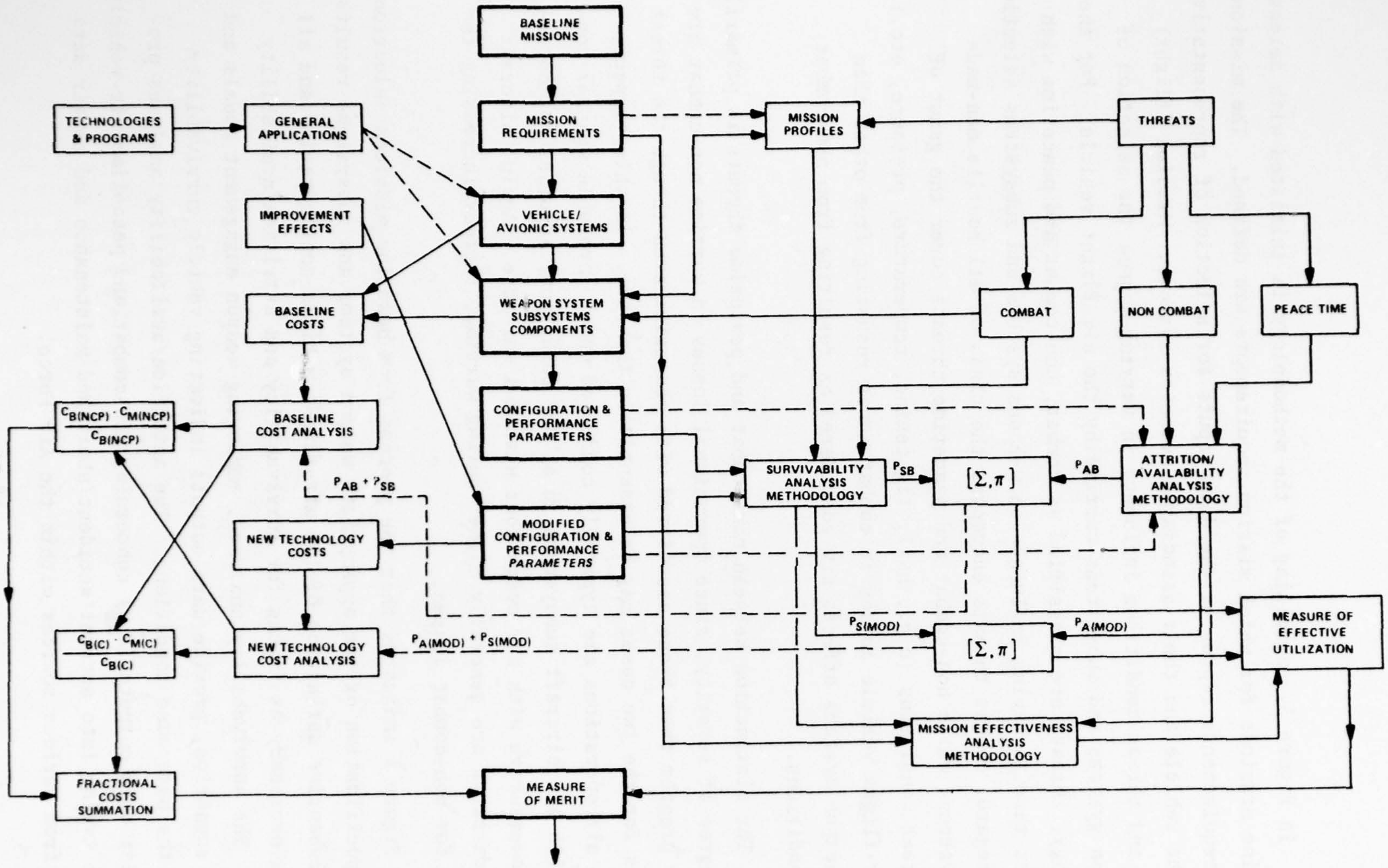


Figure 3 Methodology No.-1 Functional Diagram

In Figure 3, exercising of the methodology is initiated with selection of baseline missions for which mission requirements are defined. The mission/mission requirements represent the data inputs for selection of representative air-flight vehicle and their associated avionics systems. Mission (flight) profiles and threat conditions influence in varying degree the selection of the weapon systems and subsystems carried by the air-flight vehicle. For the methodology, threats are classified as combat, non-combat and peacetime with the combat threats having influence on weapons systems and subsystems selection. In this regard, combat threats encompass the class of all hostile man-made weapon systems, while non-combat and peacetime threats cover the gamut of other threat conditions (e.g., hail, lightening, temperature, pressure, etc.). Thus, air-flight vehicle losses in combat zones resulting from other than hostile weapon systems effects are considered as resulting from non-combat threat conditions.

The distinction between non-combat and peacetime threats is primarily one of degree of severity, since operational losses in wartime non-combat are generally greater than those associated with peacetime even though the threat conditions for the two cases may be essentially the same. In this respect, peacetime air operations are typically conducted under favorable weather conditions with all aircraft subsystems in a "Go" condition; luxuries not necessarily commensurate with air operations within a war zone. Again, aircraft utilization rates are generally higher during wartime, thereby increasing the potential for non-combat losses.

Figure 3 indicates that the process from baseline missions selection through specification of the appropriate weapon systems and subsystems results in a comprehensive definition of the air-flight vehicle configuration and all parameters necessary as inputs for survivability and attrition/availability analyses. The survivability analyses, employing weapon engagement models and specified scenarios, provide data outputs indicating vehicle survivability (P_{SB}) for the base case conditions. The attrition/availability analyses provide similar data outputs (P_{AB}) concerning non-combat and peacetime air-vehicle operations taking into account accident/abort and maintenance and repair data derivable from various sources within the Air Force.

The input of technology improvements to establish potential differences from the base case results is illustrated in Figure 3. Initially specified are the relevant technology areas and/or programs and their general application to either the air-flight vehicle or its associated weapon systems and subsystems addressed in the base case evaluations. Anticipated improvement effects for the candidate technology are shown as modifications to the air-flight vehicle's configuration and performance parameters defined for the base case. The modified parameter data is then exercised in the survivability and attrition/availability analyses to derived $P_{s(MOD)}$ for combat threats and $P_{A(MOD)}$ for non-combat and peace time threats. The outputs of the base case and technology improvement evaluations are then combined with results obtained from an independent mission effectiveness analysis to arrive at a measure of effective utilization intended to reflect a relative improvement or degradation in mission effectiveness and vehicle survivability and/or attrition.

Life cycle cost implications for the candidate technology are evaluated by first determining the acquisition and normal recurring costs associated with the base case configuration of the air-flight vehicle over a specified period of time. The results of the survivability and attrition/availability analyses are then used to modify the base line cost estimates to project life cycle costs for the unmodified configuration of the air-flight vehicle.

New technology costs are then developed. These will include technology investment and fleet retrofit costs, as applicable, and changes in overhaul and maintenance costs. These costs when combined with the survivability and attrition/availability analysis results will then yield the overall life cycle costs for the new technology.

The baseline and new technology cost analyses provide cost estimates for both combat and non-combat/peace time air vehicle operations as defined below:

- $C_{B(NCP)}$ Baseline Costs (non-combat and peace time)

- $C_{B(C)}$ Baseline Costs (combat)
- $C_{M(NCP)}$ Modified (New Technology) costs (non-combat and peace time)
- $C_{M(C)}$ Modified (New Technology) costs (combat)

Separation of the combat from non-combat/peace-time cost is warranted in that the latter costs exist more or less over the total expected life of the air vehicle while combat costs are typically developed in relation to the length, type, intensity and number of sorties conducted during the wartime conflict.

As indicated in Figure 3, the individual cost factors are combined to develop fractional cost estimates representing changes in life cycle costs, i.e. relative magnitude and direction - improvement (positive) or degradation (negative), associated with the new technology. The fractional cost estimates are then combined with the derived measure of effective utilization to arrive at the cost-benefit measure of merit for the candidate technology. The cost-benefit measures-of-merit can be used both to assess the advantage for initiation or pursuit of a specific technology program and when derived for various technology areas and candidate programs, for ranking the technologies for potential funding support.

3.3 CANDIDATE METHODOLOGY NO.-2

3.3.1 Introduction

The ordering or ranking of R & D programs for the purpose of determining their priority for support can be approached from two directions. One is the determination of the increments in capability which are achieved by supporting R & D programs through their fruition. The resultant ordering then reflects the relative magnitudes of the increased capability achieved. With the introduction of life cycle costs, a further refinement of the ranking is obtained, i.e., the relative magnitudes of increased capability achieved per dollar expended.

Alternatively, orders or rankings can also be made based on the gaps between threats and capabilities. The highest priority for R & D programs would then be assigned to those programs which contribute most towards narrowing the gaps between threats and capabilities. It is this latter approach which is discussed in the following paragraphs. Threats can be conceived and defined at various levels. At the highest level, the threat can be described in terms of national survival. At intermediate levels, a threat may consist of maintaining the integrity of border areas, whereas at the lower levels threats to specific mission objectives and flight vehicle operations become the primary consideration. This discussion is directed at the inter-relationships of threats, missions and technology at the lower levels.

The introduction and support of new technology is generally directed towards problems and threats at this level. Its successful implementation (together with political actions) will then reflect in narrowing or exceeding the gaps between threats and capabilities at the higher levels.

A schematic of the proposed approach is outlined in Figure 4 and discussed in the sections following.

3.3.2 Threat Taxonomy

Primary to the implementation of this approach is the categorization and ordering of threats. The categorization must encompass a number of factors. Among these are timeliness and uncertainty; frequency and severity/magnitude.

For example, timeliness and uncertainty associated with threats can be expressed in terms of:

1.	Current known	
2.	Future known	(3-5 years)
3.	Anticipated	(5-10 years)
4.	Conjecture	(10-20 years)
5.	Unknown	(20 + years)

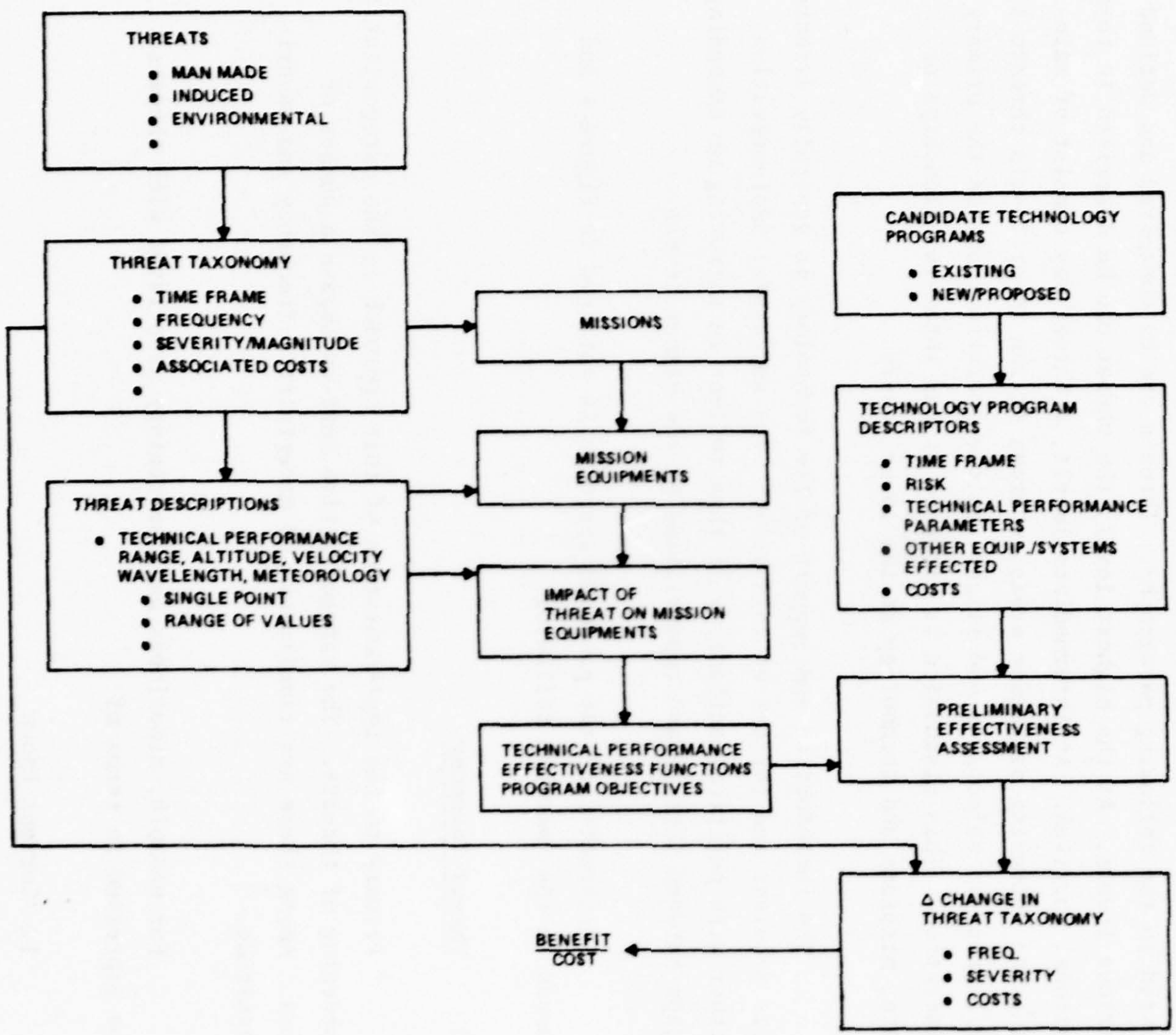


Figure 4 Threat/Technology/Cost/Benefit Methodology

The frequency and severity/magnitude of threats can be readily determined (if not on an absolute then on a statistical basis) for non-hostile threats. Applicable descriptors may include number of lives lost or injuries, equipment or system losses or downtimes; time and cost to repair or replace.

Comparable information for hostile threats is more difficult to generate; it being a function of the location of the hostile environment and the war-time scenario considered.

For the purpose of ranking, it is desirable to express all threats in terms of a single measure. The suggested one is dollars. This will require prior agreement on values to be assigned to human lives and injuries as well as weighting functions to represent uncertainties.

The final ordering of threats can be presented in a number of ways; e.g., one listing or several listings reflecting the time component of the threats.

Threat Description

The development of threat descriptors is necessary to allow the identification of the missions and the specific characteristics and attributes of mission equipment affected by the threats.

Threat descriptors consist of quantitative technical and performance parameters. They will include, as applicable, range, weight, altitude and speed data; meteorological measures, electro-magnetic emanations, etc. The parameters will be expressed as single points or ranges (upper and lower bounds) depending on their characteristics and known information of their attributes.

Threat Impact - Problem Definition

The purpose of this step is to describe how the threat affects the mission equipment. The information should include all known technical and

performance data regarding the interaction between the threat and the affected mission equipment as well as the results of the interaction.

Technology Program Objectives

Generally, there may exist several programs within a technology area and/or different technologies which offer potential solutions to a particular problem. The purpose of generating technology program objectives is to insure that all possible technologies and approaches will be considered in the subsequent analysis.

For example, a particular navigation system component may be subject to interference by electromagnetic emanations. Solutions to this problem may consist of modifying the component so that it will reject the interference or the substitution of a different type of navigation system which is not affected by externally generated signals.

Selection of Potential R & D Technology Programs

A rationale is now provided for the selection of candidate R & D programs. The objective here is to compile a comprehensive list of R & D programs which address the identified threats; not to select a preferred or optimum project for support.

Technology Program Descriptions

Each candidate program must be accompanied by descriptive information indicating:

1. Applicable time frame
2. Risk (e.g., state-of-the-art; breakthrough required)
3. Technical and performance characteristics achieved, if successful (Range: Min/max)

4. Other equipment and systems affected if implemented - how?

5. Costs

    RDT & E

    Acquisition

    Operation and maintenance

Supporting data for the above information must be provided indicating data sources utilized, underlying assumptions and the bases for deriving the costs. This is essential to insure that the subsequent selection of preferred programs for implementation can be conducted in a fair and equitable manner.

R & D technology programs which address a particular problem identified as a technology program objective may not exist. In this instance, the technology program objective will provide the basis for soliciting new concepts and approaches.

Preliminary Effectiveness Assessment

This step consists of an initial screening of the candidate R & D technology programs based on their potential effectiveness, timeliness and overall impact on system operations. The particular form of analysis required will depend on the problem area and technology.

Programs whose probability of success is found to be marginal will be eliminated from further consideration at this point.

Final Assessment of R & D Technology Programs

The technology programs which survive the initial screening will be examined to determine the extent to which they reduce the threat cost as determined previously (Threat Taxonomy). The cost reduction achieved can be expressed as a measure of merit as follows:

$$\frac{C_{TR} - C_{TP}}{C_T}$$

where

C_{TR} = Cost of reduced threat

C_{TP} = Cost of technology program

C_T = Initial threat cost

C_{TR} represents the new threat cost after implementation of the technology program. C_{TP} is the cost of implementing the technology program and includes RDT & E, acquisition and O & M costs. C_T is the threat cost as determined earlier. The measure of merit thus represents a benefit/cost ratio.

3.4 CANDIDATE METHODOLOGY NO.-3

3.4.1 Introduction/Concept

The technologist often finds himself competing with other technologists for resources to perform research programs. A decisionmaker* therefore attempts to divide a finite and insufficient set of resources between the competing technologists in a good and hopefully optimum manner.

The decisionmaker would naturally like to know how to rate the proposed programs on the basis of some measure of value. This methodology proposes to calculate such a measure as the expected relative increase in Air Force effectiveness per life-cycle dollar per research investment dollar. There are major pitfalls in attempting such an undertaking and these are

*The decision maker is identified, for example, as the commander of AFFDL.

discussed at length in Reference 1. A separate section discussing this methodology relative to the pitfalls indicated in the reference is included below.

In spite of the problems indicated in the reference, the TES program is also attempting to integrated both peacetime and wartime effectiveness into the calculus. A little reflection will confirm that the timing, length and intensity of any future conflict will affect competing technologies unevenly. A proposed solution to this problem is discussed in the final section.

TOTAL AIR FORCE MISSION EFFECTIVENESS

The Air Force, Congress and the Executive set policy which results in the distribution of operational air power. The R & D planner-analyst must accept the appropriateness of this decision as indicating an optimum allocation of national resources. If the allocation is optimum, then the marginal utility of aircraft in the inventory is equal. More simply, the nation views a $\$10^8$ increase in F-15s purchased as no more useful than a $\$10^8$ worth of FB-111Hs or KC-135s.

Now this equality-of-marginal-utility state is a reflection of a number of social and political factors as well as some mathematical realities such as the lack of utility for an additional "Air Force One" aircraft. It is assumed that the marginal values can be taken to be locally linear in the sense that a utility increase in any one segment of the Air Force can be related to a different utility increase in some other (possibly partially overlapping) segment of the Air Force. If one can determine the changes in aircraft utility that a technological change introduces as well as the expected cost impacts, then an overall rating system is possible.

If the above premises are accepted, one now possesses an extremely powerful tool for evaluation of any proposed change in aircraft technology. The power of the technique has to do with the ability to defend the "weighting

factors" which in other cases (see Ref. 1) are heuristic at b st but, more importantly, are derived from "experts" who are not the policymakers. The real policymakes could hardly be expected to accept the type of survey required to find out their weighting factors now could one expect to have all of them appreciate the difference between total and marginal utility.

Figure 5 illustrates the principal elements and their interrelation as envisioned for this candidate TES methodology. The following paragraphs discuss the implications of each of the blocks of Figure 5.

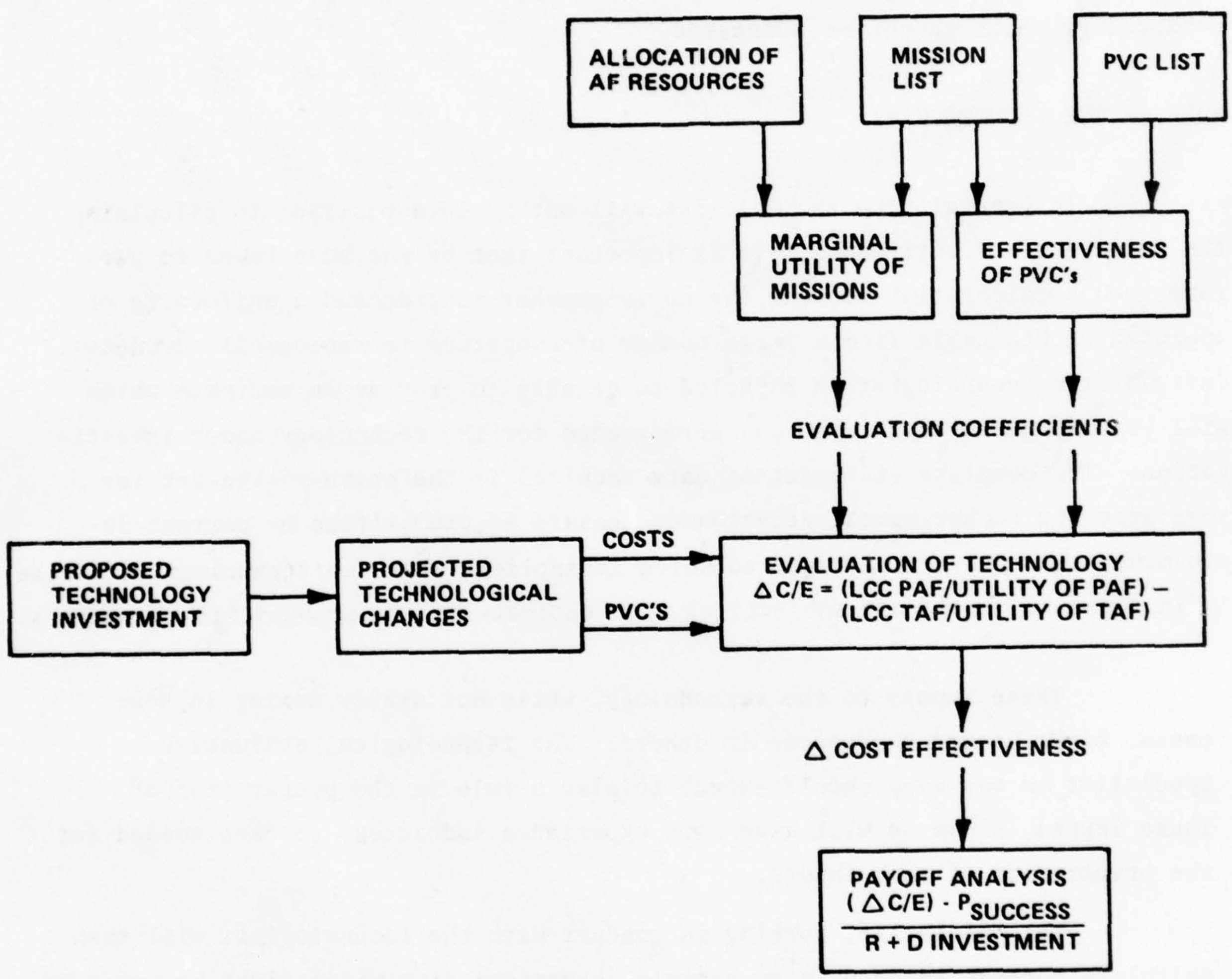
UTILITY FUNCTIONS

The development of utility functions is the major technical challenge in the methodology. A utility function is defined as the utility of an aircraft in a particular mission. One needs to establish its current utility and the change of utility per nominal change in the primary vehicle characteristics such as range, speed, vulnerability, etc.

The development of utility functions should proceed along the lines that each aircraft type has a spectrum of missions to perform. Hopefully, the analyses which led up to their performance specifications will be available. If not, they will have to be postulated. In any event, examination of the marginal performance variations of the aircraft in its mission environment with respect to marginal changes in primary vehicle characteristics should yield a utility value for the primary vehicle characteristics.

Any given aircraft can perform many different missions and, depending upon the particular war, may be allocated to these missions differently While this is a theoretical problem, it does not appear to be a practical problem. It is believed that the allocation of the forces with multimission

TOTAL AIR FORCE EFFECTIVENESS METHODOLOGY



PVC PRIMARY VEHICLE CHARACTERISTIC
PAF PROJECTED AIR FORCE
TAF TECHNOLOGICALLY IMPROVED AIR FORCE
LCC PEACE TIME LIFE CYCLE COST

Figure 5 Methodology No.-3 Functional Diagram

capability can be made such that each aircraft type will be dedicated to a single mission in a defensible way for a relatively wide spectrum of conflicts. If this is not possible, at least single-type-aircraft blocks can be defined in which all aircraft in a block have a single mission role. Once this allocation is made, it appears that there are no major unsolved problems in the methodology which cannot be addressed.

ROLE OF THE TECHNOLOGIST

In general, the technologist will not be in a position to calculate the measure of effectiveness. It is important that he not be allowed to perform such a calculation because the decisionmaker must demand a uniformity of approach unobtainable from a large number of competing technological advocates. Instead, the technologist is expected to be able to provide an estimate which will be some measure of technical performance for the technology under investigation. The complete statement of data required is the state-of-the-art for some specific technological performance measure as exemplified by current deployment, the types of aircraft to which it applies, what the technology will likely increase to, and, most subjectively, an estimate of the probability of success.

These inputs to the methodology, while not overly taxing in some cases, might become burdensome in others. The technological evaluation specialist in any case should expect to play a role in the preparation of these inputs, since he will have more experience and access to data needed for the preparation of such inputs.

The specialist, working in concert with the technologist, will then calculate corresponding primary vehicle characteristics which might be achieved by the pursuit of the proposed technology.

With the quantification of the technological output in terms of the primary vehicle characteristics, a uniform basis of comparison can be obtained and the measures calculated by the relatively straightforward means described below.

RATING METHODOLOGIES

Multiple Objective Additive Weighting

The validity of the existing methodologies is severely limited by a failure to achieve in reality the necessary assumption that goals of the methodology must be linearly additive. To explain this problem one must consider two possible evaluation techniques.

Multiple Objective Additive Weighting (MOAW) means that one can construct a set of M objectives and I alternatives. For each alternative we must be able to evaluate the contribution of alternative i to objective m for all i and m. The best alternatives are those whose value V_i is largest where

$$V_i = \sum_{m=1}^{M} I_m C_{mi}$$

where I_m is the "importance" of objective m

and C_{mi} is the contribution of alternative i to objective m

Necessary conditions for the validity of this approach are:

A. The contribution of an alternative in achieving an objective must be independent of the contributions of other alternatives.

B. The rate of substitutions of value or utility between two objectives must be constant.

C. The goal structure must be complete.

D. The contributions must be determinable.

E. The importances must be believable.

F. Uncertainty must enter the calculus.

The following paragraphs discuss the above criteria in turn.

A. The independence of contributions is a particularly hard criteria to meet. Reconnaissance forces are nearly useless when no weapon delivery systems exist and in reverse, weapon delivery systems are enhanced by reconnaissance forces.

B. The rate of substitution of value is theoretically achievable since one explicitly considers the importance of each goal.

C. The completeness of the goal structure may be faulty due to:

- Incomplete awareness of the problem at hand
- Incomplete knowledge of the intricacies of the problem.
- Inability to devote sufficient effort to formulating a complete list.
- Fear that the real objectives are not politically palatable.

D. Evaluating contributions is not always easy.

E. Deriving valid importance coefficients especially where they are a function of the level of the alternative available is not always easy in practice.

F. Uncertainty is not easily treatable. *For instance, if there is* an even chance to save 2×10^9 defense dollars with one alternative and a chance to save 10^9 dollars with near certainty on another, the utility for each is not necessarily the same (Ref. 4).

In another light there may even be a "cost" in terms of embarrassment for failure beyond the sunk cost of the unsuccessful research program. Some agencies will prefer high-risk, high-payoff programs while others will support only sure things. Thus, chance itself may have either positive or negative utility.

Multiple Attribute Additive Weighting

More preferable is the approach of multiple attribute additive weighting. (Reference 1 notes that this approach under certain circumstances is equivalent to the multiple objective schemes.) This methodology is a multiple attribute approach.

The value of an alternative V_i is a function of a J-component attribute vector (a_{ij}), weighted by an importance function W_j and a utility function $U(a_{ij})$. This is expanded as follows:

There are K missions in the Air Force, (strategic bombing, tactical battlefield, airlift, etc.). Associated with each mission is the cost of the force, r_k, dedicated to that mission. Finally, there is a set of J attributes called primary vehicle characteristics. The existing force level of each attribute is a_{ij}. The likely level of each attribute as a result of the proposed research effort is b_{ij}. The relative utility of a given primary vehicle characteristic toward each mission is given by coefficients u_{jk}. The value then of the i^{th} program, if successful, is:

$$V_i = \sum_k r_k \sum_j (b_{ij} - a_{ij}) \quad u_{jk}$$

The methodology is feasible since:

- o The r_k are matters of record.
- o The a_{ij} and b_{ij} are feasible to estimate by the technologist or analyst.

- The u_{jk} can be derived from mission analysis efforts.

SOLUTION TO THE DURATION OF CONFLICT PROBLEM

For the purposes of this methodology most conflicts can be simply quantified by a duration, time frame and intensity. However, a three-dimensional dependence of the results will be completely intractable. The total Air Force mission effectiveness approach can rely on its fundamental assumption of the optimization of the utility of forces over the expected spectrum of conflict has been accomplished. One can assert with this assumption the marginal interchangeability of utility between mission effectiveness for different missions. The methodology can then use, as the value of a technological improvement, the change in total Air Force effectiveness divided by the peacetime life-cycle cost. This is quite tractable.

3.5 METHODOLOGY COMPARISONS

The selection of the recommended TES methodology is based on a number of considerations, chief among which are the ability of the methodology to provide priority ranking of threats and relevant technologies, adaptability to the range and breadth of potential candidate technologies, the credibility of the approach and the practicality of the methodology. The latter term is defined here to include efficiency and visibility. Efficiency refers to the ability to identify and circumscribe a problem area in order to minimize the analytical effort required to achieve meaningful results. Visibility refers to the user of the methodology being able to discern clearly how the results are obtained.

The initially postulated TES methodology (i.e. candidate NO-1)represented an attempt to combine all pertinent considerations into a conceptual framework. The primary point of entry into the methodology was baseline missions from which mission requirements, associated air vehicle systems/subsystems, and relevant configuration and performance requirements were derived. Candidate technologies and threats represented secondary points of entry. The

driving force, however, were the baseline missions. This approach has a number of shortcomings. The primacy of baseline missions tends to limit the scope of the methodology to current types of operations. It is likely to foreclose from consideration new technology requirements and new and novel approaches to satisfy these requirements. Again, the methodology fails to generate technology requirements independent of responses to the requirements and does not develop a priority ranking of threats. It does not readily permit the assessment of problems of limited scope without exercising the entire methodology.

The starting point of the second iteration of the TES methodology (i.e., candidate No-2) was a listing of threats. This point of entry was selected in recognition of the fact that missions are planned and technology programs are supported in response to existing or conjectured threats. The final payoff in all cases being the negation of the threat.

A threat is generally conceived as a physical act -- a bird striking a windscreen or a SAM launched at an air vehicle. Actually, threats encompass a much broader range of activities. For example, the rising costs of weapon system acquisition and operation and the shortage of skilled personnel to operate and service air vehicle systems are also threats to the national defense and survival. Such threats are in fact recognized; witness the support of technologies directed towards the reduction of acquisition and operations costs and the development of computerized fault-finding and instructional systems.

The shortcomings of this methodology are in the areas of technology evaluation and relating the technologies to the identified threats. Specifically, consideration of the relationships of candidate technologies to performance and mission effectiveness, improvement in air vehicle survivability and required tradeoff analyses between costs incurred and technology and mission performance parameters are insufficient to obtain a priority ranking of the candidate technologies.

The third methodology considered represents a distinctly different approach. It is based on the concept that past and present funding and air vehicle acquisition programs represent optimum allocations of the funding. If the allocation is optimum, then the marginal utility of each air vehicle system in the inventory is equal. If one can determine the changes in aircraft utility that a technological change introduces as well as the expected cost impacts, a rating system is possible since a utility increase in any one segment can be related to a different utility increase in some other segment of the Air Force (given that the marginal values are linear over the ranges of values considered).

The approach addresses total Air Force effectiveness and planning requirements at the macro level. As such, the results obtained by exercising the methodology can be expected to provide Air Force priority guidelines at a point in time.

The types of technology implementation decisions, for which the program methodology must provide support, however, is at the micro level. The initial range of uncertainty present in the computation of the utility functions at the macro level must be expected to become quite large when applied at the micro level.

Whereas this approach is conceptually appealing, it appears doubtful whether acceptable values can be computed at the level of detail and specificity necessary for the assessment of new technologies.

The recommended TES methodology, described in Section 4, is derived from all three methodological approaches discussed previously. It is designed to eliminate the weaknesses and shortcomings as described in this section.

SECTION IV

TES METHODOLOGY - MODULE DESCRIPTIONS

4.1 INTRODUCTION

The recommended TES methodology is designed to assist Air Force planners in selecting technology investment areas which aid in alleviating identifiable threats to air-flight vehicle performance and survivability. The methodology permits the identification and subsequent ranking of problem areas amenable to the application of technology improvements and then allow ranking or prioritization of alternative technology investments based upon the combined factors of survivability, mission effectiveness, and costs.

The main thrust of the TES methodology is to assess the influence of advancing and new technologies on threats to air-flight vehicles within an operational frame of reference. The terms "*advancing and new technologies*" immediately suggest that the methodology will in large measure, deal with technology candidates for which few analytic, computer, simulation, or other evaluation tools will exist at the point in time when they are most needed. In this respect, recognition is given to the fact that the methodology must address a diversity of technology types as applied to a spectrum of both current and postulated new threats. Further, that consideration be given to technologies spanning the range from Basic Research (at the 6.1 level) through Exploratory Development (6.2) to Advanced Development (at the 6.3 level).

The development of appropriate technology models or simulations as part of the TES methodology probably represents an unrealistic solution to the above difficulty. This is based on (1) the anticipated large number of models or simulations that would be required to cover the diversity of technology areas falling within the scope of the methodology, (2) the uniqueness and specialized characteristics of such models and difficulties that would be encountered in quantifying the essential attributes of technology candidates in relation to specific threat and air-flight vehicle problems (particularly at the Research and Exploratory Development stages), (3) the limited utility of specialized

technology models, (4) moderate to high model development costs and, (5) lack of timely availability. The selected approach for the methodology therefore is primarily proceedural in nature with computer models or simulation being used in a supportive role for selective situations. As such, emphasis of the methodology is directed to providing a team of analysts with an ordered sequence of steps considered as essential for establishing threat rankings, potential worth of candidate technologies to alleviate identified threat problems, and cost-benefit data supportive for ranking of the technologies.

An overview of the recommended approach to the TES methodology was presented in Figure 1 of Section 2 along with brief descriptions of the functional steps involved for ranking of technology investments relative to identified threat problems. An expanded version of the methodology annotated with the functional steps shown in Figure 1 is presented in Figures 6 and 7. As suggested by the use of two figures, the overall methodology consists of two distinct yet related evaluation processes. The first, illustrated by Figure 6, involves the identification and ordering of technology requirements which result as a direct consequence of the systematic identification and ranking of the multitude of threat situations confronting air-vehicle operations. This process facilitates the detailing of technology deficiencies, ordering of threat air-vehicle problems, establishment of technology goals and specification of technology requirements. The second portion of the methodology illustrated in Figure 7 is designed to select, evaluate and rank those technology programs (i.e., recommend solutions to problem areas) which are responsive to each set of technical requirements defined in the initial evaluation process. Each element of the recommended methodology is discussed in the following subsection.

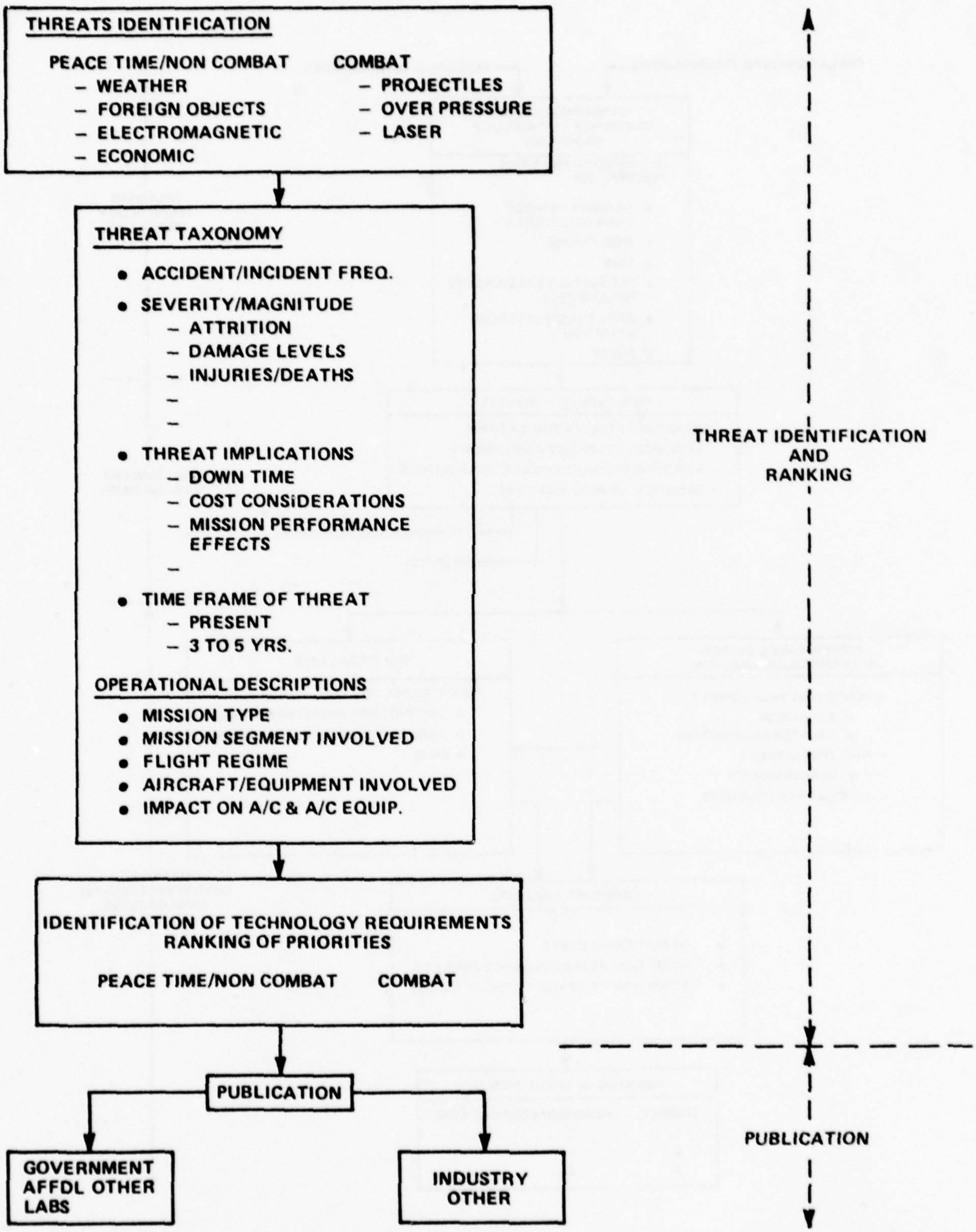


Figure 6 Recommended TES Methodology (Part - 1)

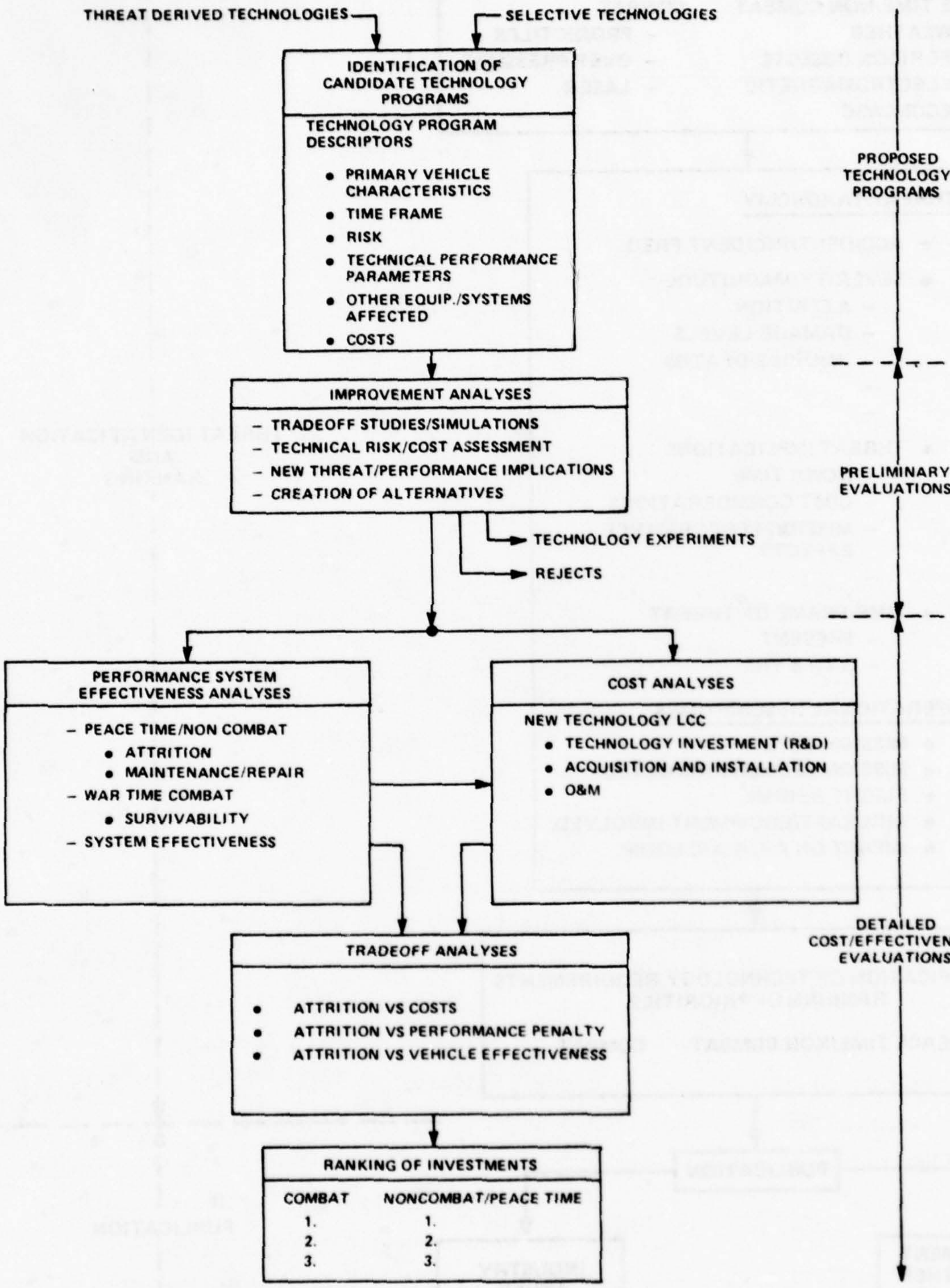


Figure 7 Recommended TES Methodology (Part - 2)

4.2 METHODOLOGY DISCUSSION - MODULE DESCRIPTIONS

4.2.1 Threat Identification and Ranking Module

Initial emphasis in the methodology is given to the identification and ranking of all threats which affect the operational readiness and use of air-flight vehicles. The threat identification process involves the collection, review, and evaluation of information obtained from Air Force records, data banks, and other sources concerning the types, causes, conditions, severity (material and economic), and frequency of occurrence of operational problems associated with each type and class of air-flight vehicle. The derived "problem statistics" then serve as the basis for both war time and peace time threats identification and ranking. The problem statistics also provide essential information for establishing threat-related technology goals and requirements.

The threat classification, threat taxonomy, and threat ranking/technology requirements blocks of Figure 6 represent the principal elements encompassed by the threat identification and ranking module. The purpose of and requirements for each of the blocks are described in the following paragraphs.

4.2.1.1 Threat Classification

The classification of potential threats to air-flight vehicles involves the selection of threat categories and the identification of relevant threat types within these categories. The threat types may be categorized as environmental threats (e.g., hail, airframe icing, bird strikes, etc.), induced threats (e.g., aerodynamic heating), and man-made threats (weapon-related hazards such as laser energy, blast overpressure, projectiles and fragments). The environmental and induced threats occur both during peacetime and wartime flying, but the accident/incident rates may vary because of different flight profiles and mission abort criteria. Combat threats (i.e., man-made threats associated with weapon systems) must be treated separately because of the critical sensitivity to assumptions of engagement scenarios, threat mix, and threat densities.

The decision to use threats rather than capabilities as the point of departure in the methodology has a significant effect on the outputs of the methodology. In this regard, the final output of the selected approach assigns the highest priority to those technologies which are most cost-effective in countering or alleviating the severest threats. Using capabilities as the starting point, however, poses a potential problem in that one might be tempted to assign the highest priorities to technologies which offer the greatest potential improvement beyond current capabilities. This could result in a higher priority rating for a technology which offers a large improvement where current capabilities are already adequate as compared to a technology which offers a lesser improvement in an area where the current capability with regard to the same threat situation is clearly inadequate or marginal.

Development of the threat categories and identification of threats within those categories requires that an extensive survey be conducted to obtain a comprehensive listing of actual and potential combat and noncombat threats. The survey should include literature searches and interviews with cognizant DoD agencies. A partial list of potential information sources to be screened for development of the threat classification data is presented as follows.

- Accident/Incident Data

  USAF Safety Center (AFISC), Norton Air Force Base, CA

  - Computer Data by Cause, Type Aircraft, System Affected, etc.

- Maintenance Data

  Maintenance Management Information and Control System (MMICS)

  - Computer Data Stored in Compliance with AFM 66-1/T.O. 00-20-2 Day to Day Maintenance Records by System, Type Work, Hours Spent, etc.

- Specialized Reports

  Other Reports Generated to Promote Flying Safety

  - Hazard Reports (HR's) - Accident Potentials Reported by Operational Personnel

  - New Monthly Report from all Units to Comply with AFR 27-15 "Birdstrike Hazard Reduction" AFISCF (Norton AFB)

- <u>Aircraft Utilization Data</u>
  - Hours flown by Aircraft Type - Compiled IAW AFR 65-110
- <u>Expert Opinion</u>

  Information Supplied by Personnel from AFLC Air Material Areas
  - Programmed Depot Maintenance, and Operational Units Required to Assist in Proper Interpretation of Computer Data

Although it appears desirable to collect a comprehensive list of threats, some bounds must be established in the interest of objectivity. The suggested bounds are references to data, reports, or simulation results which support the contention that a particular threat currently exists or will exist for a proposed technology advance or future type air-flight vehicle. This requirement serves two functions; one, it precludes the inclusion of pure (unfounded) guesses and personal bias in the development of the list of threats, and two, it provides the analyst with necessary input information for the evaluation and ranking of the threats. Information for potential (future) threats would be formulated on the basis of (1) an understanding of current threat/equipment problems, (2) anticipated equipment system changes which shift threat emphasis, (3) logical suppositions as to the operational use, deficiencies and vulnerabilities of new systems, and (4) state-of-the-art and technology pursuits of both U.S./Friendly and Hostile countries.

4.2.1.2 Threat Taxonomy

The identification of a threat does not provide a measure of its severity, frequency of occurrence, importance, or the circumstances surrouding its occurrance. These factors, jointly, form the basis for the establishment of the threat ranking. The threat taxonomy, therefore, involves the analysis of data collected during threat classification to derive information regarding the specifics of aircraft attrition and/or the degree of damage associated with each threat by air-flight vehicle type. In this respect, it is recognized that a threat generally does not exist independent of an item of equipment or system, its technical and performance characteristics and operational mode. For example, the significance of birdstrikes as a threat depends on the flight altitude, speed, size and angle of the windscreen of the air-flight vehicle. Thus, birdstrikes may represent a minimal threat to small, slow utility aircraft and severe threats to fast, low-flying aircraft such as the F-111.

The development of detailed threat descriptions is analagous to the need for an accurate diagnosis before a remedy can be selected and a cure achieved. The detailed threat descriptions, therefore, provide the inputs for the selection of appropriate analyses, models and measures of effectiveness for the evaluation of proposed technology programs. This allows the development of the evaluation process to proceed once the threats and technology requirements have been specified.

Procedure Description

As indicated above, the threat taxonomy involves analysis of collected data with respect to the frequency, severity, time frame and implications of each threat type. The data analysis activity provides information regarding the frequency of aircraft attrition and damage associated with each threat by aircraft type. Having assessed how often the threat occurs, the severity or magnitude of the problem is examined. The measures of severity include attrition levels (i.e., number of aircraft lost), damage levels (e.g., man-hours to repair), the number and severity of air crew injuries and the number of deaths attributable to the threat. After the threat frequency and severity data are analyzed, it is possible to examine the implications of the threats in terms of cost, system availability, and mission performance.

The frequency and severity of the threats impact cost in terms of aircraft attrition, aircraft repair costs and aircrew replacement costs. Aircraft damage also implies aircraft downtime, while parts are obtained and replaced, which in turn adversely affects aircraft availability. The threats may also have identifiable impacts upon mission performance in terms of the probability of successfully completing a given mission type.

In the categorization of threats, it is useful to sort the threat types with respect to the time frame of the threat (i.e., current threat or projected threat 5 to 10 years hence). The threat time frame is significant because the candidate technologies which may be applied against a particular threat all have some minimum elapsed time required to develop and apply the

technology to operational weapon systems. The time required to implement the candidate technology must obviously be consistent with the time frame of the threat.

The evaluations of natural, induced and man-made threats will be measured from different bases. The data base for natural and induced threats will be the recorded events of accidents and incidents. As indicated above, such data generally provide the specifics of the occurrence including fatalities and injuries, the extent of physical damage, and the time and cost to repair or replace. The resultant information can be used on an aggregated basis or extrapolated to represent postulated air vehicle mixes, fleet sizes and air vehicle operations. The same approach is applied to man-made threats, but to a lesser extent. Combat histories of recent conflicts may provide some useful inputs. To a large degree, however, the potential impacts of man-made threats will have to be derived from analyses and computer simulations. The results obtained will necessarily reflect the input assumptions and the limitations of the analyses and simulations. Additionally, different models will have to be employed for different man-made threats. The models will vary with respect to the level of detail and accuracy with which they represent real world situations.

In addition to developing data concerning the frequency, severity, time frame, and implication of each threat type, operational descriptors relating air vehicles to the where, when and how a threat occurs, must be determined. Further, the descriptors must be developed to the point whereby technologies which have potential to counter the threats, either in total or in part can be identified. The operational descriptors include:

- Aircraft/Aircraft Equipment Involved
  - F-4, F-106, B-52, ...
  - Radar, Navigation, ...
- Impact on A/C and A/C Equipment
  - Structural Failure
  - Mechanical Failure

- Hydraulic Failure
- Engine Failure
- Electrical Failure

- Mission Type
  - Interdiction
  - Reconnaissance
  - Close Air Support
  - Logistics/Supply
- Mission Segment
  - Refueling
  - Ingress/Egress
  - Weapon Delivery
- Flight Regime
  - Low/High Altitude
  - Takeoff/Landing
  - Maneuvers

To develop the operational descriptors, information and data sources (e.g., page 42) would be reviewed to ascertain and quantify for each threat type, the air vehicles and equipments involved, the type failure/problem incurred and the circumstances in which the particular threat is encountered. The review/quantification process would be conducted at the macro rather than micro level so as to identify (with minimal effort) the principal circumstances associated with individual threat/air vehicle problem from which new technology goals/requirements would be defined.

Identification of the air-vehicle systems, subsystems and components which encounter a specific threat aids in determining the extent to which a threat is either design specific (e.g., unique to the F-111 aircraft), applies to an entire class of aircraft (e.g., all fighter aircraft), or is common to all air vehicles in the Air Force inventory. Identification of the aircraft subsystem or component impacted by the threat (e.g., windshield) is a prerequisite to the selection of appropriate candidate technologies to counter the threats.

The detailed specification of the impact of threats on the air vehicles (i.e., type of failure) and missions is necessary not only for the selection of candidate technologies but also to facilitate the evaluation of

the technologies. For example, a threat may only impact on one air vehicle component (windshield) during low altitude flight at air vehicle speeds exceeding a particular speed. In this case, the evaluation of candidate technologies can be limited to that air vehicle component and the specified flight regime. In effect, the definition of the specific circumstances under which the threat interacts with the air-vehicle and/or its subsystem permits bounds to be established concerning the type and extent of analyses, simulation, etc., that would be required to determine the value of candidate technology improvements.

The threat taxonomy must be periodically reviewed, modified, and updated. Reasons include the introduction of new technology weapon systems or the development of new intelligence. Regardless, however, the threat taxonomy probably will never be all-inclusive.

New technology programs may be proposed which appear to have merit but which do not correspond to any identified technology requirement. In such instances, two actions may be implemented. One is the evaluation of the proposed program similarly to that of any other program. The other step is to review the implications raised by the program to determine whether it responds to a previously unidentified threat and, if so, its magnitude and severity.

As previously noted, following the initial compilation of the threats list and related threat "problem statistics," the data should be reviewed and updated annually or biannually. The data compilation is estimated to require 1-4 manweeks per major threat considered.

4.2.1.3 Threat Ranking/Technology Requirements

Up to this point, the recommended TES methodology has centered on the development of comprehensive descriptions of all environmental and man-made (hostile) threats which interact with each specific air-flight vehicle for its intended operational usage and the extent and type of influence which each threat exerts on the vehicle performance, mission effectiveness, maintainability and operating costs. The desired threats list and related "problem

statistics" provide the basis for both peace and war time threat ranking. In addition, the data provides essential information for establishing technology goals and requirements for alleviating the identified threat problem. Discussions addressing the ranking of threats and the intent for development of technology requirements are presented in the following paragraphs.

Threat Ranking

The ranking of the natural and induced threats can be accomplished in a straight-forward manner. Rankings of the man-made threats will require the exercise of engineering judgment because of the differences in the sources from which the data are derived. It is anticipated that only large differences in the severity of threats as determined by the exercise of the models can be considered significant. As a result, the assignation of man-made threats to a 3 or 4 step threat categorization ranging from severe to slight may be more realistic and acceptable then an individual ranking of each man-made threat.

The ranking of threats requires their expression in common, comparable units. The proposed index is

$$I_T = P_{(E/S)} \times C_E \times N_{F/I} \times C_S$$

where

I_T = Threat Index

$P_{(E/S)}$ = Engagement Probability/Sortie

C_E = Average Cost/Engagement

$N_{F/I}$ = Number of Systems or Equipment in the Fleet or Inventory

C_S = Cost of System

The index incorporates measures of threat frequency and severity and mission importance.

The engagement probability per sortie is a measure of the likelihood that a particular threat is encountered in the course of a sortie. Engagement probabilities per flying hour or per blocks of flying hours (e.g., 1000 hrs) could be employed in lieu of engagement probability per sortie. The term "engagement" in this context is defined to include all events which can impact on the survivability of an air-flight vehicle.

The average cost per engagement is a measure of the severity of the threat. It is the maintenance, repair or replacement cost attributable to the engagement. The number of systems or equipment in the fleet or inventory are used as a proxy for the threat frequency. The system cost (unit acquisition cost) is employed as a weighting factor to represent mission importance.

The index permits the quantification of noncombat and combat threats on a common basis. Two of the factors $N_{F/I}$ and C_S are essentially constants. The engagement probability/sortie (e.g., birdstrikes) and the associated repair and/or replacement costs can be calculated from peacetime flying hour and maintenance records. The derivation of the latter factors for combat threats requires the use of engagement and mission models and simulations or the results, therefrom. The outputs of the mission models are strongly scenario dependent.

The proposed approach allows threat costs to be developed and presented either on a system or aggregated basis. For example, the cost of bird strikes on windscreens can be determined initially on a per vehicle basis (F-111, F-4, etc.). The sum of the resultant threat indices then represents the total magnitude of the threat of bird strikes to air vehicles. Other types of threats, i.e., SAMs and AAMs can be evaluated in a similar manner.

The combining of noncombat and combat threats into a single ranking list appears to be of questionable worth. This conclusion is based on the realization that combat threats account for the vast majority of air-vehicle losses to the Air Force with peacetime and noncombat losses generally falling into the category of occasional or rare events on a comparative basis. Threat indices

derived for noncombat and peacetime conditions, therefore, are expected to be significantly smaller than those derived for combat. Consequently, any combined ranking of combat and noncombat threats would, in most instances, relegate the latter to the bottom of the threat listing.

The noncombat threats are in general based on historical data, accident reports, maintenance actions, etc. The combat threat index cannot be derived in the same manner. The reason is that one must "assume a war" in order to predict the relevant parameters. The mission, training, and general aviation activities of aircraft in peace time are serving in part as surrogates for the war time activities of these aircraft in terms of the noncombat threats. The index of importance attempts to reduce the impact of the assumption but does not eliminate a strong dependence on the intensity of the assumed war time operations.

In the proposed approach for hostile threats, a future composition of the Air Force is constructed based on Air Force planning documents. From a list of missions, the fleet is decomposed into components which perform these missions. Each component is assigned to one mission type. In some cases an aircraft type (e.g., A-7) could be assigned to only one mission (e.g., Close Air Support). This would not preclude some other type (e.g., A-10) from being partly or wholly assigned to that same mission (e.g., A-10 - 40% Close Air Support and 60% Battlefield Interdiction). As the future Air Force composition changes so can the mission mix of assignments. The missions themselves are defined in terms of enough parameters that further analysis can be performed to determine the effect of performance changes. In general, a specific representative profile is drawn and published.

The quantity, C_E, the average cost per engagement, in most cases will be computed on the basis of the probability of kill, P_k for the threat in the particular phase of the mission times C_S. The probability of kill per engagement is derivable from several sources. In general, these are unsatisfactory for various reasons. Calspan believes that the BLUE MAX/BETA/TAC ZINGER models currently operational at AFFDL represent one of the better if not the best capability to derive P_k data and should be utilized for this purpose.

The engagement probability per sortie is the most difficult parameter to fairly estimate. Combat commanders in tactical conflicts such as Viet Nam tend to adjust the probability of encounter so that the loss rate is a near match to the replacement rate. Furthermore, historical conflicts do not contain all the threats of interest (e.g., with respect to SAMs, the popular press did not report any SA-3, SA-4, SA-5, SA-6, SA-8 or SA-9 in Viet Nam).

Modern warfare requires that defense suppression activity receive a major emphasis whenever encounters are likely. Thus, the probability of encounter cannot be based on the density of threats but must include consideration that the threat may be killed, engaged elsewhere or unwilling to engage.

It is proposed that engagement probabilities be obtained from mission analysis activities conducted by various government agencies. Particular agencies which are currently engaged in appropriate large-scale mission analysis efforts from which such engagement probabilities could be obtained are:

USAF Mission Analysis Facility - WPAFB
AF Studies and Analysis - Pentagon
ESD - Hanscom AFS, MA
Strategic Systems Program Office - WPAFB

Technology Requirements

The threat-air-vehicle descriptions i.e., threat lists and related problem statistics) disclose specific areas where and the severity of conditions for which technology investments are likely to represent cost-benefits to the Air Force. Again the descriptions, having been developed in the main, from data derived from reports issued by operational commands, maintenance depots, and etc. will permit the recognition of technology goals and requirements.

The technology requirements can be viewed as lists of vehicle and/or subsystems performance parameters which must be met in order to either resolve or at least improve (reduce) the threat problems. The requirements, therefore, must be carefully constructed in that they must be sufficiently detailed and

precise to define threat/air-vehicle problems, while at the same time general enough so as not to exclude potential solutions to the problems, particularly where the solutions may involve the application of new or innovative technologies. In the limit, the identified technology requirements can be viewed as the type of information normally assembled by the military for either outlining in-house program objectives and requirements or used as the basis for development of RFQs for issuance externally to industry.

4.2.1.4 Module Summary

The principal outputs of the threat identification and ranking module will be the priority rankings of noncombat and combat threats, quantitative/qualitative descriptions of the threat air-vehicle impacts and the identification of technology requirements based on the latter.

Reference Data

Representative data sources have been identified earlier in subsection 4.2.1.1 pertaining to threat classification.

Implementation Plan

Development of the threat listings and related problem statistics and technology requirements is considered a principal feature of the TES methodology. A pilot study is warranted, therefore, to determine the extent to which such data can be assembled and organized into a format beneficial to the Air Force. Specifically, the study would address the detailed examination of between three to five noncombat threats in relation to (1) data sources, requirements, and extent, (2) applicable analysis and data processing programs, (3) development of individual threat indices, statistics, and related technology requirements, and (4) threat rankings (between the related candidate threats). A similar procedure would be followed to examine a number of combat threat candidates.

The candidate threats would include samples which are judged as representative of:

- Severe Threats
- Moderate Threats
- Minor Threats

so that the validity of the threat index can be established. Further, the selection of threat candidates should be based on experience concerning their relative importance at least in qualitative terms, so that comparisons are possible between preconceived judgments and computed values. The comparisons will provide an initial estimate of the credibility of the proposed approach for establishing threat priority ranking and whether or not the results obtained are justifiable in terms of expended efforts.

4.2.2 Publication Module

The results of the threat identification/ranking process provide the Air Force with comprehensive listings of air-flight vehicle threat problems for which technology improvements are desired. In addition, the results form the basis for soliciting from both government and industry sources, technology inputs specifically responsive to the identified threat problems. Publication of the threat listings and related information, therefore, represents the first step in the formulation of technology programs considered to be of timely interest and value to the Air Force.

The purpose for publication of the threat listings and technology requirements is to alert and/or update scientific and technical personnel in industry, government, and the academic community of identified threat problems so as to enhance the potential for obtaining the widest possible range of solutions. Publication of the threat listings is considered similar to, yet distinct from, the current publication of AFFDL programs in that the threat listings emphasize problems to be solved while current AFFDL publications describe continuing and planned programs with only incidental reference to problem areas.

Procedure Description

Publication of the threat listings involves the periodic issuance of a technical report describing (1) the threats, (2) their relative importance and related problem statistics, and (3) technology goals desired to relieve same. Classification of the report would be either Unclassified or at least held to the lowest possible level consistent with data contexts and intended distribution. Special classified supplements could be envisioned for threat listings pertaining to wartime combat threat problems.

The "Threat Identification and Ranking" report, as noted above, would be reviewed by a diversity of government agencies and laboratories, industry contractors, universities, and individual scientists. Some format for response with indications as to the type and depth of technical information desired needs to be developed. This submission format would serve both to standardize (to a limited extent) all responses while providing assistance to those unfamiliar with Air Force procurement practices. Further, to encourage inputs from the totality of the technical community, and particularly from sources that might be unfamiliar with related technical and/or operational implications of their inputs on air-flight vehicles, and therefore might project unique or novel approaches to specific threat problems, a special submission process is recommended.

The Army addressed the latter area above with the establishment of its Advanced Concept Team functioning under the Office of the Director of Army Research. Inputs to this team are encouraged through submission of a short (approximately three pages) information brief covering:

- Delineation of a technical problem area
- Summary of a proposed concept or approach
- Expected impact on military operations
- Technical feasibility and high risk areas
- Expected availability date
- Estimated costs and basis for estimates

The information brief is reviewed by a team of specialists to assess the general merits of proposed concepts, identification of unrecognized problem areas and recommendations for implementation to both the proponents of the concept and the military.

The benefits derived from publication of the threats listing and technology goals are candidate technology program proposals addressing Air Force needs. These proposals take the form of research programs with specific sources identified (e.g., in-house or specific contractors with unique capabilies or facilities), research programs with a competitive procurement proposal, unsolicited proposals, and suggestions from individual scientists and engineers. Implementation of the publication process would be under direction of the commander of AFFDL.

4.2.3 Proposed Technology Programs

The mainstream of candidate technology programs are expected to originate in response to the published threat listings. Additional candidates can originate, however, independent of the threat identification process as "selective technology" programs which enter the methodology as shown in Figures 1 and 7. These selective technology programs are representative of the various activities typically supported by, for example, AFFDL for improving air-vehicle performance development of advanced capabilities, etc.

All of the proposed technology programs, as indicated in Figures 1 and 7, would be subjected to a preliminary evaluation or screening (Improvement Analysis in Figure 7) to assess essential program attributes and establish gross technical and/or cost benefits. The preliminary evaluations serve as the basis for either rejecting some candidates for further examination while accepting others for detailed performance/system effectiveness and cost analyses.

Data necessary for conduct of the improvement, performance/system effectiveness and cost analyses (Figure 7) must to a major extent be provided as part of each proposed technology program as "Technical Program Descriptors."

These program descriptors represent detailed technical and performance descriptions relating the candidate program to either an identified threat problem or projected advancement in air-vehicle performance or capability (for selective technologies). The technical descriptors provide such information as:

- Primary vehicle characteristics - how the technology affects the performance, survivability and effectiveness of the air vehicle.
- Time frame - development and procurement lead times, i.e., expected IOC date.
- Risk - a statement of the likelihood of attaining the program objective(s) and of anticipated problem areas.
- Technical performance parameters - impact of the technology on the air vehicle weight, speed, range, etc.
- Other systems/components affected - the need to modify or enlarge installed equipment, e.g., the requirement for large amounts of electrical energy for new equipment may necessitate either a larger engine and generator or an auxiliary power unit.
- Costs - an estimate of the development, acquisition and operating costs of the technology; i.e., the incremental LCC of the air-vehicle resulting from the implementation of the technology.

The descriptions will be provided by the proponents of the candidate technologies and will serve as the basis for the evaluation of the technologies. The data provided may be modified by the evaluation analyst. This may be necessary to compensate for overly optimistic estimates by the technology proponents and/or to assure that competitive technologies are assessed and compared on an equitable basis.

4.2.4 Improvement Analyses Module

Introduction

The purpose of the improvement analysis module is to provide an examination of the basic economic and technical aspects of proposed programs. Preliminary investigation and screening of technology candidates is to be conducted independent of many related operational and long-term cost factors.

It is anticipated that technology improvements covering a diversity of technical areas and scientific disciplines will be proposed. Depending on the specifics of a candidate technology, the type of analyses, depth of investigations, and level of effort required to define its position in rank or priority relative to all other (including non-related) technology candidates can be expected to vary over wide limits. In most cases, preliminary examinations of the essential attributes of each technology program will establish gross technical and/or cost benefits for the technology before subjecting it to more rigorous (and possibly unnecessary) evaluation.

The objective of the improvement analyses module is to identify and exercise analysis and evaluation procedures capable of establishing for each proposed technology, its basic worth to alleviate the addressed threat or air vehicle problem. The analyses will establish as much as possible, the technical feasibility, the principal cost drivers, and the potential limitations inherent to the technology area associated with the proposed technology program.

The results of the improvement analyses take the form of recommendations for further action, identification of data or information deficiencies, and assessments of technical and economic risks. The recommendations per se may include the deletion of low-yield programs (those judged to provide little collective improvements in technical performance and cost reduction); elimination of the cost, mission effectiveness or survivability analyses based on identified low impacts in these areas; or possibly, the more rigorous examination of a technology candidate using the cost, mission effectiveness, survivability and tradeoff modules. Each candidate technology program is viewed as a proposal

submitted by a proponent to achieve a given goal or objective. The proposal, in general, will originate in response to published threat-related technology requirements or as an independent input to apply a projected technology advance to a general threat area, for improving some vehicle performance characteristic or for the generation of an entirely new operational capability.

Procedure Descriptions

Collectively, the technology proposals will vary significantly with respect to program complexities required to achieve intended objectives, technical areas of interest and extent and validity of supportive technical and economic data. Despite the indicated disparities between proposed programs, some type of procedure is required to assess the basic worth of each technology candidate; a procedure which is both flexible and adaptable to all technology programs yet provides essentially the same generic type decision information for each, independent of the technical area of interest. The selected procedure for the improvement analyses takes the form of a proposal evaluation process.

Under the methodology, each and all candidate technology programs would be reviewed and screened by a staff of "proposal" evaluators. This staff (possibly in conjunction with the proponent of the technology program) determines the credibility of each technology proposal by establishing and using generic evaluation measures addressing, for example, technical feasibility, technical performance parameters, data deficiencies, performance and cost implications, etc. Thus, problems associated with gross disparities between technology proposals are resolved first, by using the generic evaluation measures and second, by maintaining flexibility in the composition of the proposal evaluation staff; that is, by varying the number and "expertise" of staff members commensurate with the particulars of each technology proposal.

In the main, the preliminary evaluation of a proposed technology program involves judgments of staff personnel qualified in the technology areas associated with candidate programs. The selection of an evaluation procedure will depend on the specifics of the technology program and the extent of

technical advance anticipated beyond current capabilities. As an initial step therefore, staff members of an evaluation team determine the nature of a candidate technology program, defining goals and objectives, program evaluation costs, decision points, etc., and the "expertise" required to conduct the evaluation process.

The preliminary evaluation process addresses specific points of inquiry, as for example:

- Relationships of the technology candidate to identified threat-air vehicle problems for which technical requirements may already exist.
- Identification of a technical goal or level of performance for which the proposed technology advance represents an improvement over existing conditions.
- Technical feasibility of the proposed program to achieve the technical objectives defined by the program descriptors and identified technical acceptance level.
- Identification and preliminary assessment of cost drivers that are inherent to the technology area proper.
- Assessment of technical risks.
- Projected impact of the technology on overall air-vehicle performance characteristics. (Required as input data for the Performance/Mission effectiveness analyses.)
- Projected impact of the technology toward the generation of new (or different) threat problems thereby reducing the technical or economic value of the proposed technology change.
- Creation of alternatives for use of the technology.

The evaluation staff may conduct limited tradeoff analyses or simulations so as to "check" the validity of selective aspects of a proposed program. The maximum extent of such analyses or simulations are envisioned as

one to four man-week efforts dependent upon the nature and value of the technology candidate. Simulation would involve the use of existing or possible limited modification of existing models, as contrasted to new model developments. In selective technology areas, acceptable analysis/simulation capabilities may exist in other government facilities or be available from the proponent of the technology program or some other outside source. Some analysis/simulation therefore conceivably could be conducted external from the evaluation staff but under its direction.

Inputs

The inputs to the improvement analysis take the form of proposed research efforts from many sources. As a preliminary step, it is likely that some type of standard format should be adopted and all suggested programs be placed in this format. Proposed technology investigations generated internal to AFFDL will, of course, be supported by Air Force documentation. For convenience, external inputs can be placed in an abbreviated version of that format so that all proposals can be equally treated.

This module could also be a source of proposed technology programs. In the course of the improvement analysis, a given program may be judged to be too risky or insufficient data may be available for a good decision. It is a reasonable outcome for an analyst to be assigned to create a data gathering program to support the original proposal which for the present will be held in abeyance pending the results of the newly created effort. This type of resolution is expected when a high-risk/high-payoff technology is involved.

Reference Data

There is no specific reference data for this module. As time goes by a large store of reference data will be collected by the analysts.

Output

The results of the improvement analysis process are recommendations for the disposition of technology candidates. The recommendations can take the form of a deletion of a technology candidate without further investigation,

continuance of detailed evaluation and ranking, foreshortening specific portions of the evaluation process or possibly formulation of technology experiments to verify questionable data inputs (which re-enter the methodology as additional proposals).

Included in the output must be a documentation of the expected interaction of the technology if pursued. Both favorable and unfavorable interactions are expected and must be identified.

Implementation Plan

The implementation of this module will consist of establishing procedures for accepting proposals for technology from a number of different sources in the form of program documentation (internally generated) and abbreviated program documentation form (external input). Much of these procedures are already in place and functioning within the AFFDL commander's staff.

The mechanisms are the current program control and unsolicited proposal management system. A new feature of the TES methodology is the activity of making an evaluation of the established AFFDL program elements on an equal footing with other inputs. Also of importance is the separation of evaluators and proponents. The proponents of any technology must not be tasked to evaluate the good and bad features of their proposals. These actions are properly within the scope of the assignment of the AFFDL commander.

4.2.5 Effectiveness/Survivability Evaluation Module

Introduction

The objective of the effectiveness analysis is to provide quantified values for changes in the effectiveness and survivability of Air Force systems in future time frames given specific states of various technologies during these time frames.

The effectiveness analysis attempts to quantify the changes in performance and survivability of air-flight vehicles under the assumption that some performance measure is improved. Effectiveness analysis enters the methodology in two places. Formally, it enters the analysis of proposed research efforts. However, the "Baseline Air Force" without technological change is also to be processed through the methodology in order to quantify the threats. The input is descriptive material on time-phased technological improvements. The outputs are time-phased survivability and effectiveness for each mission expressed as a ratio between the baseline and improved vehicle. Inputs for the effectiveness analysis are the assessments of each proposed research effort as accomplished by the preliminary assessment step. In some cases this assessment will have provided sufficient parametric representation of the expected results to proceed with the evaluation. In other cases, the assessment will provide only sketchy data. In these cases, the inputs will have to be estimated before evaluation can proceed.

Procedure Descriptions

In most cases, in the description of proposed research programs, the success measures which are quoted and the deployment schedule will be sketchy and incomplete. A first step in the procedure is to develop these elements fully. It is important for the methodology to recognize and account for the fact that any proposed research program will have a proponent who, in general, has his or her time, prestige, career success and many other important values at stake in the success of the proposal in winning support. At the same time, this proponent is probably the best technical expert in the proposed field.

Recognizing these factors, a means for a full, fair and complete analysis of each program must be developed. Every effort should be made to avoid the pitfalls of unfair analyses. The rating system can neither ignore or completely rely on the proponent in the development of proposed program descriptors. In the recommended approach, members of the AFFDL commander's staff will be assigned to develop predictions as to reasonable initial and total R&D costs and schedules, expected performance increments and expected purchase and O&M costs. In this portion of the methodology, only the performance and survivability aspects are of concern.

In the technique for the formal evaluation of survivability and performance, a set of standard missions are established. For each mission, a single performance measure is developed which is a function of a list of technical performance characteristics (TPC) (e.g., range, velocity, weight, cross section, etc.), a subset of the primary vehicle characteristics. Similarly, a survivability measure is developed for encounters with each of the identified threats. For each mission there is a set of encounter probabilities which are also functions of the TPCs. These functions can all depend on time-frame also. (For example, if a threat is predicted for phase-in or phase-out.)

The performance for a baseline air-flight vehicle is then relatable to a technologically improved vehicle to determine the value of the proposed improvement. This is accomplished in terms of performance and survivability ratios here but ultimately the measure will be in terms of a common dollar equivalent in the tradeoff procedure.

The system to perform this formal analysis will probably be computerized. The program itself will be quite simple. It is expected that this portion of the methodology, once developed, will require relatively little time to execute. Data preparation should take only a few man-days and the execution of the computer program will be nominal. Approximately one calendar-week will be needed to evaluate any proposed program. During this period, a

number of programs could be processed simultaneously. This module will be the most critical element in the methodology in terms of visibility for the disappointed proponents and for critics of the methodology. Because this module embodies predictions of future air-vehicle employment, it is essential that all actions and parameters be well documented. Furthermore, since the generalizations necessary to make the methodology work are broad and far reaching, every effort must be expended to assure that the relationships in the evaluation methodology are the best possible estimates of the future. It is, therefore, imperative that the parameters of the methodology be constantly under review and updated as appropriate.

Because of this criticality, rigid software management and control must be maintained on the computer program. At all times the "production" version of the evaluation program should be simultaneously available to a wide spectrum of users. (Proponents should be able to use it to see what has high payoff.) At the same time, no one should be able to modify it without publication and staff review of proposed changes. Thus, the program must be readily usable and copyable, but the production version should be impossible to modify without proper authorization. It is anticipated that changes might be frequent at first. Thus, good programming practice and documentation will be an important characteristic.

Implementation Plan

It appears that a two-phase effort to implement this portion of the methodology is required. In the first phase, a preliminary set of performance, vulnerability, and encounter frequency functions would be developed for an equally preliminary set of missions. This effort could be implemented either in-house or with contractor support for any or all portions of this part of the methodology. Since this module is so central to the threat identification and candidate program evaluation, it is essential that it be available early in order to begin to exercise the methodology. Building a part of the methodology on an interim basis with the expressed intention to modify or replace it in the future will allow AFFDL more flexibility to experiment without being forced to make irreversible decisions as to the details of the methodology.

The second phase should begin after at least one procurement cycle (fiscal year) of full-up use of the interim methodology has been accomplished. In the second phase, the interim functional relationship will be updated and replaced on a systematic basis.

The particular items to be developed are:

- A listing and description of a standard set of Air Force missions.
- A matrix giving the relative frequency of encounter for each threat during each mission for the time frames of interest.
- A set of functional relationships giving the effect of the TPCs on each of the missions for the time frames of interest.
- A set of functional relationships giving the effect of the TPCs on survivability given an encounter for each mission threat and time frame.
- A list of TPCs and the baseline Air Force TPCs as a function of time frame.

The functional relationship in the activities to be pursued in the development of the module are depicted in Figure 8. The sources of data are indicated in Table 1.

The level of effort to create inputs, obtain reference data, and to provide management of the computer program is estimated to be about two man-years per year. The initial effort to obtain the preliminary mission effectiveness and survivability functions is estimated at $75K over six months. The computer program is estimated to cost an additional $50K and would be developed during the same time period. Contractor support for an initial exercising of this portion of the methodology is estimated to require $40K over six months.

<u>Inputs</u>

The inputs to this module are the proposed research efforts which were judged by the screening analysis to be worthy of consideration and which

TABLE 1
REFERENCE DATA REQUIREMENTS

Data Type	Source Phase I	Source Phase II	Form	Notes
TPC List	This Effort	Modified as Required	Simple List in TR-2	
Mission Descriptions	AFFDL Staff	Modified as Required	TR-1*	
Baseline TPC	AFFDL Staff	AFFDL Staff	TR-2	Issued Periodically (1-3 year intervals)
Mission Effectiveness Functions	AFFDC, ASD or Contracted	Modified In-House	TR-3	
Survivability Functions	AFFDL, ASD or Contracted	Modified In-House	TR-3	
Threat Descriptions	Developed elsewhere in Methodology			
Survivability Effectiveness Computer Program	Contracted	Modified In-House	Computer Program & Documentation	

*Formal technical reports

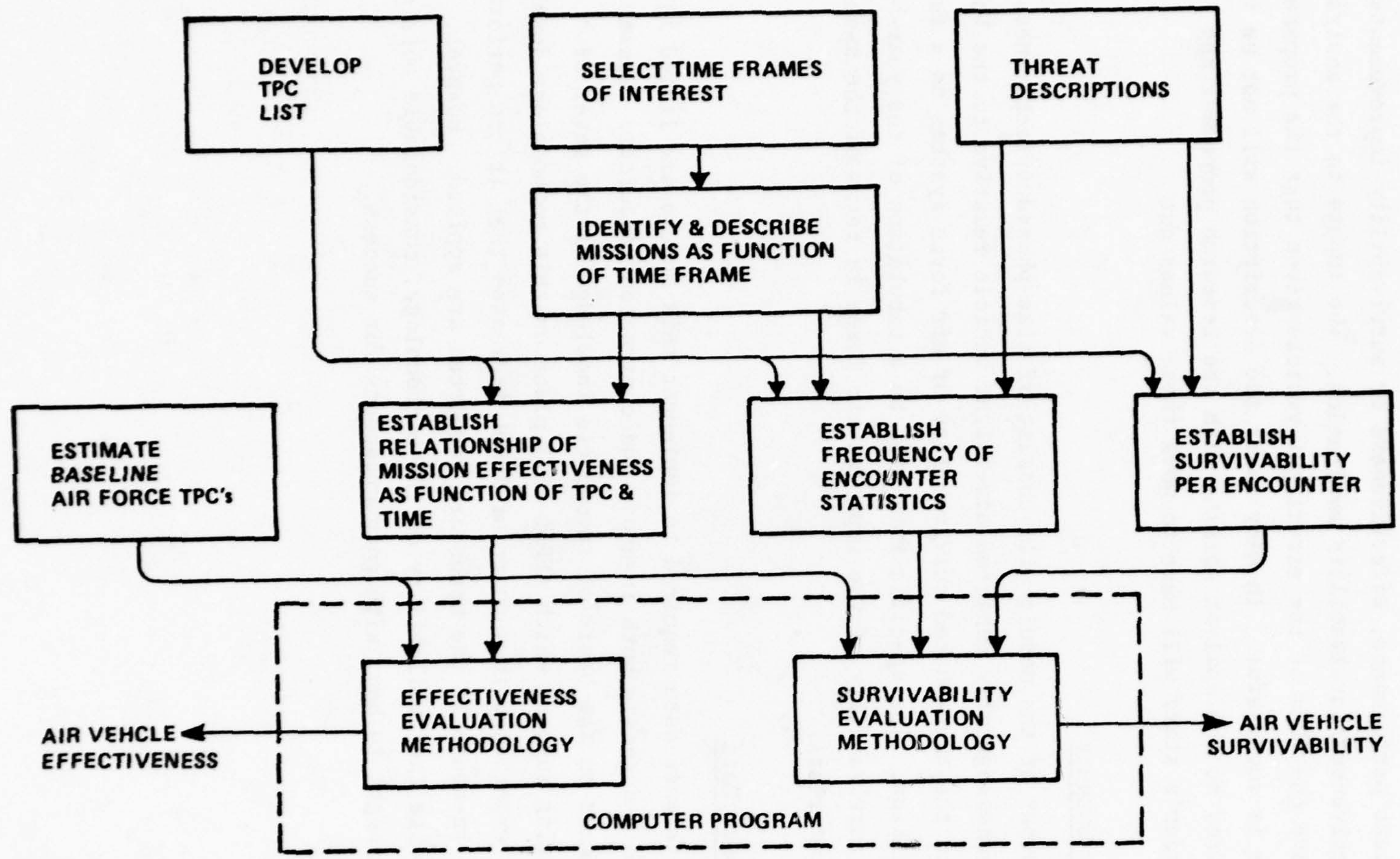


Figure 8 Development of Effectiveness/Survivability Methodology

promise significant performance, effectiveness or survivability improvements to warrant an effectiveness/survivability evaluation. The inputs to the analysis in this module are the TPCs of the air-flight vehicle given that the proposed research program is successful. In many cases the description will not be in the detail required so the analyst working with the research proponent and the AFFDL commander's staff will have to work these values out.

Module Outputs

The output of the module will consist of time-phased effectiveness ratios of the technologically enhanced air-flight vehicle relative to the baseline vehicle, and the time-phased survivability of air force systems as a function of threat and mission. The specific form will be a tabulation of the year-by-year performance and survivability of the improved air force in terms of the specific mission and threat lists.

Reference Data

The reference data required to implement this module are listed in Table 1. The table suggests both in-house and contracted resources. These suggestions are made on the basis of incomplete knowledge of the level of priority and funding support which AFFDL will place on this methodology development. Calspan's experience in support of AFFDL indicates that it can perform most of the work in-house if the necessary resources are applied. However, in order to expedite the availability of the methodology, considerable outside support can be brought to bear with good prospects for success.

4.2.6 Cost Analysis Module

Introduction

Cost considerations, taken in conjunction with system effectiveness and schedules are the essential elements of the DOD system management process. They are the determinants of whether a program should be initiated and subsequently whether to discontinue it or proceed to acquisition, implementation and operation.

The central element of this module is the development of costs relevant to decision-making. The use of dollars as a key measurement unit provides the common basis for the comparison of alternative systems and programs.

The terms "cost-effectiveness" or "cost-benefit" analysis describe the major thrust of the proposed methodology. In the assessment and choice of alternatives, the decision-maker must consider the cost of acquisition and all future expenditures associated with an alternative and compare these costs with the future benefits which result from each alternative. The term life cycle cost specifically denotes the inclusion of subsequent costs along with initial investment costs.

The selection of the time horizon is a critical element of the LCC decision process. This selection must be made carefully for each technology program based on the expected or intended life of the program.

The choice of the "time horizon", will determine whether cumulative cost lines cross during or after that life (if they cross at all). Also, the time horizon affects the quantitative difference between alternative LCC technology program values. In cost-effectiveness or cost-benefit analyses it is the quantitative difference in costs which is compared to the quantitative value of effectiveness or benefit which is of primary importance to the decision-maker.

Procedure Description

Various methods for developing costs may be employed. Depending on the technology program being considered and its stage of development, costs may be based on gross engineering estimates, derived from cost estimating relationships (CERs), actual costs incurred or combinations of the foregoing.

The application of engineering cost estimates will be limited to technology programs which are in their early stage of development and whose technical characteristics and performance parameters cannot be related to earlier programs.

The development and/or use of CERs will be the most prevalent method for generating required costs. The latter will include RDT&E, acquisition and installation, operations and maintenance costs and their aggregation into life cycle costs. Considerations in the development of these costs can include procurement quantities, identification of sunk costs, and the assignment of expenditures by fiscal year.

Costs models which incorporate appropriate CERs may exist and will be used when available. In other cases, extant models may be adapted to the technology program under consideration.

Actual costs will be used when the new technology program includes off-the-shelf equipment or incorporates on-going activities.

The level of effort necessary to generate the required costs can vary widely depending on the technology program and the availability of pertinent costs, CERs and cost models. On an average, however, 1 - 3 manweeks are estimated to be required to assemble the cost information for a technology program.

Inputs

The data base necessary to generate the required costs generally will include the following information:

- Technical and performance characteristics
- Applicable existing cost models

- Historical costs and cost/performance data for analagous systems/equipment
- Standard cost factors

Reference Data

The data sources, apart from general references such as maintenance and repair records and general cost manuals such as AFR 173-10, USAF Cost and Planning Factors, will be technology dependent.

Implementation Plan

The costs can be generated either by in-house or contractor cost analysts who are familiar with the technology program being considered.

4.2.7 Tradeoff Analysis Module

Introduction

The evaluation of technology programs occurs at various levels--from detailed design specifications to overall performance requirements. Different measures of effectiveness may apply as development proceeds from RDT&E through production and operation.

The objective of this module is to select and utilize a set of measures of effectiveness which in combination with system performance, effectiveness data, and systems costs will assist the decision-maker in the selection of the "best", (i.e., cost-effective) program or systems from alternative candidate programs or systems. The results can take one of two forms: (1) the greatest effectiveness achieved for a given level of expenditure, or (2) the least costs incurred to attain a postulated level of effectiveness.

The immediate study objective is concerned with the survivability of air-flight vehicles in the face of natural and man-made threats. Enhanced air vehicle survival, however, is not necessarily in consonance with air vehicle performance and general system effectiveness, i.e. the measures of effectiveness representing survivability, air vehicle performance and effectiveness are not always

compatible. For example, increased survivability may be achieved by the addition of armor to protect vital components. The added weight, however, can reduce the air vehicle range and payload.

Procedure Description

The principal areas of interest are the assessment of the candidate technology programs in terms of their impact on air vehicle survivability, performance, effectiveness and costs. The analyses generally will be in the form of a comparison of alternative technology programs where the latter include the existing system, equipment or operation.

Cost vs enhanced survivability comparison can be presented in a number of ways. One is to show the difference between the damage and loss costs associated with the extant technology (C_{OT}) and the comparable costs incurred with the candidate new technologies (C_{NT}); i.e., $C_{OT} - C_{NT}$.

The above comparison does not account for the expenditures incurred to achieve the new technology. The inclusion of these costs yields a net cost, i.e. $(C_{OT} - C_{NT}) - NC_{NT}$ where the latter term represents the net costs incurred to acquire, operate and maintain the new technology .

This presentation of costs can also be expressed as a benefit/cost ratio, $\frac{C_{OT} - C_{NT}}{NC_{NT}}$.

Comparisons can be made on a unit equipment and fleet or inventory basis. For technologies which address peacetime threats, the comparisons will be made primarily using annualized costs over the remaining life span of the *systems or equipment.* Direct comparisons between candidate and extant programs can then be made in terms of the present value of the cost streams. The cost streams will also be used to conduct break-even analyses to designate cross-over points and potential savings, if such occur.

Combat threats must be evaluated differently, since annual costs are not relevant to combat operations. The threat data derived previously includes the engagement probability/sortie and the cost/engagement. Comparable data will have been developed for the new technology programs as part of the improvement and cost analyses.

Candidate technology programs, in order to qualify as viable alternatives must demonstrate improvement in terms of the combination of engagement probability/sortie and cost/engagement. Combination is underlined since a large reduction in the engagement probability/sortie accompanied by a small increase in the cost/engagement can also result in an overall cost saving.

Comparisons of technology programs will be made parametrically with number of sorties and cost/engagement as the independent and dependent variables, respectively.

It is recognized that technology programs implemented to enhance the survivability of air vehicles can have adverse effects on the performance characteristics and effectiveness of the air vehicles. Examples are increased weight, reduced operating range and payload. In many instances, the changes will be relatively small.

Such changes will be documented and presented as part of the descriptive information provided with each of the technology programs being considered.

Inputs

The major inputs utilized in this module are the outputs of the improvement analyses and the cost analyses.

Outputs

The outputs of this module will be the comparative analyses between the candidate and extant technology programs in terms of changes in survivability, costs, performance characteristics and effectiveness of air-vehicles.

Implementation

The required analyses can be performed by in-house or contractor engineers/scientists and cost analysts. It is estimated that the postulated tradeoff analyses can be completed in 1-2 man-days for each set of technology programs, i.e., alternative technology programs which address a particular threat.

Ranking of Investments

Separate rankings will be shown for technology programs which address combat and noncombat threats. The threat index (I_T) defined in the threat taxonomy module description will provide the basis for establishing the rankings. Specifically, the rankings will be based on $I_{T(OT)} - I_{T(NT)}$ where the former represents the threat index with the old or present technology and the latter term the threat index with the new technology in place.

The technology programs which demonstrate the largest difference between $I_{T(OT)}$ and $I_{T(NT)}$ will be assigned the highest rank. The remainder will be ordered by decreasing size of the differences.

Descriptive information will be provided with each of the ranked technology programs. This will include:

- Costs - RDT&E, acquisition, O&M and LCC
- Attrition reduction achieved
- Benefit-cost ratio, potential cost savings, break-even point
- Impact of technology on air-vehicle performance characteristics and effectiveness

SECTION V
QUALITATIVE ASSESSMENT OF TES METHODOLOGY

5.1 INTRODUCTION

Application of the candidate TES methodology to the spectrum of technology areas of interest to the Air Force represents a critical point of concern under the program. In one sense, the methodology may be required to demonstrate technology program worth based on a minimum of available input data and in the limit with only generalized indications as to the association of the technology with a specific improvement in an air-flight vehicle and/or in its operational performance. In an alternate sense, significant and fine grain data may be available from Air Force data banks pertaining to existing threat-air vehicle problems for which technology deficiencies and/or requirements have been or could be developed. Furthermore, cases will exist whereby one may be required to estimate or project the degree of improvement (e.g., 10% reduction in weight) that could be realized through application of a technology. The technology improvement (and estimated degree thereof) then would be evaluated using the methdology to assess operational performance effects on vehicle survivability and mission effectiveness and ultimately to determine the implications of life cycle cost.

As indicated in Section 4, the methodology is primarily procedural in nature with analysis and computer models or simulations being employed on an availability basis. Further, as discussed in Section 4, the specifics of a threat problem and candidate technology to relieve it, will impact on the type and depth of evaluations required under the methodology for determining the threat index (and ranking among many threats) and cost benefits for the technology candidate. The following sample exercise is presented therefore to illustrate the use of the methodology.

5.2 QUALITATIVE ASSESSMENT OF BIRDSTRIKE PROBLEM

The sample exercise represents a qualitative assessment of the birdstrike (threat) problem to transparencies (wind screen/canopy) of the F-111 aircraft. As an initiating step, a subjective classification of all natural

and induced threats is presented in Table 2 for reference. The hostile man-made threats are listed in the table for completeness. The severity and frequency of occurrence for each threat are indicated by the ranking symbols on the following basis:

LEVEL OF SEVERITY	1. Critical to all flights
	2. Affects all flights
	3. Affects primarily peacetime training flights
	4. Negligible effects on any flight
FREQUENCY OF OCCURRENCE	A. Common
	B. Occasional
	C. Rare

As indicated in the table, the birdstrike problem is considered critical to all flights since bird engagements under any flight regime could result in damage or loss of the aircraft although the frequency of such incidents is rated as occasional.

The basic input data required for development of the threat statistics for the F-111 birdstrike problem is derived from sanitized* computer printouts received from the USAF Safety Center at Norton AFB.** An example of one computer printout for a specific incident is shown in Figure 9. Selective data extracted from the Safety Center printouts for F-111 canopy/birdstrike incidents covering a five-year period (1972-1977) is given in Table 3 with an explanation for the column headings of Table 3 given in Table 4.

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*Sanitized data deletes any reference to pilot identification and injuries sustained, judgmental opinions on human error, etc.

**Additional data sources would be searched under normal utilization of the methodology.

Table 2

PRELIMINARY ASSESSMENT OF THREATS

SEVERITY FREQUENCY	THREAT	SEVERITY FREQUENCY	THREAT
		NATURAL	
1B	BIRDS	1B	HAIL/SLEET
3A	CLOUDS	1B	ICE
?C	COSMIC RADIATION	1C	INSECTS
2A	DENSITY	4C	OZONE
4B	DEW/HUMIDITY	3C	POLLUTION, AIR/SALT SPRAY
1B	LIGHTNING	2B	PRESSURE, AIR/VAC
1B	FOG	2A	RAIN
1C	FUNGI/SPORES	3C	SAND & DUST
4C	GASES, DISSOCIATED	1B	SNOW
4C	GASES, IONIZED	4C	SOLAR RADIATION
3C	GEOMAGNETISM	2B	TEMPERATURE/GRADIENTS
1B	FROST	2B	TURBULENCE/WINDS/GUSTS
		1C	WIND SHEAR
		INDUCED	
2A	ACCELERATION/MECH SHOCK	1A	HUMAN FACTORS
4C	ACOUSTICS	2C	MAGNETIC FIELDS
2C	AERODYNAMIC HEATING	2B	MOISTURE
1C	EXPLOSIVE ATMOSPHERE	1A	NUCLEAR RADIATION/FLASH
1A	FOREIGN OBJECTS	2A	VAPOR TRAILS/EXHAUST SMOKE
4C	GASES, DISSOCIATED/IONIZED	2B	VIBRATION
		2C	ZERO GRAVITY

HOSTILE

AAA – ANTI-AIRCRAFT ARTILERY	AIR LASER WEAPON	SAL – SURFACE TO AIR LASER
AI' – AIRBORNE INTERCEPTOR	SMALL ARMS	SAM – SURFACE TO AIR MISSILE

Table 3

SELECTIVE CANOPY/BIRDSTRIKE INCIDENT DATA FOR F111

A/C TYPE	DAM/INJ	WUC	HRS. REP	OPS PHASE	ALT/AS	TYPE MISSION	OTHER DESCRIPTIONS
F111	SL/NO R	–	35	LOW LEVEL FLT	500/500	LLNAV	SMALL BIRD
F111	SL/NO	16ABA	2	LOW LEVEL FLT	3500/480	GND ATK.	NIGHT
F111	SL/NO	16ABE	15	LOW LEVEL FLT	1000/480	LLNAV	SMALL BIRD
F111	SL/NO R	–	30	LOW LEVEL FLT	1000/480	LLNAV	SMALL BIRD
F111	SL/NO	–	48	LOW LEVEL FLT	1000/480	LLNAV	
F111	SL/NO	–	0	–	–		SMALL BIRD (NIGHT)
F111	SL/NO	–	0	–	–		SMALL BIRD (NIGHT)
F111	SL/NO	16ABE	80	LOW LEVEL FLT	500/480	LLNAV	SMALL BIRD (NIGHT)
F111	SL/NO R	16AAC	144	LOW LEVEL FLT	1000/480		
F111	SL/NO R	–	20	LOW LEVEL FLT	1000/450	LLNAV	
F111	DESTROYED/ NO	–	–	NORMAL FLT	?	PILOT CHECKOUT	EJECTED BECAUSE HE COULDN'T SEE. RADIATION SHIELD SMASHED CANOPY
F111	SL/NO	16ADD	2	CLIMB	2500/350	PILOT CHECKOUT	
F111	SL/NO R	16ACC	48	RANGE	1000/480	GND ATK.	
F111	NO/NO	–	–	LOW LEVEL FLT	1000/450	LLNAV	
F111	SL/NO R	16AAD	12	LOW LEVEL FLT	1500/450	LLNAV	NIGHT
F111	SL/NO R	16AAD	18	LOW LEVEL FLT	200/450	GND ATK.	2 SMALL BIRDS
F111	NO/NO	–	–	LDG APP	1000/250	–	NITE
F111	SL/NO	–	–	RWG	3500/400	GND ATK.	
F111	NO/NO	–	–	LDG APP	1500/250	–	
F111	SL/NO	11ACD	48	RANGE	1000/450	GND ATK.	
F111	SL/NO R	16AAC	6	RANGE	2500/400	GND ATK.	NIGHT PILOT COULD NOT SEE. WSO HELPED
F111	NO/NO	–	0	RANGE	–	GND ATK.	
F111	SL/NO R	16AB6	30	LOW LEVEL FLT	500/450	LLNAV	
F111	SL/NO R	16AAD	17	LOW LEVEL FLT	500/450	LLNAV	
F111	DESTROYED/ MAJOR	–	–	LOW LEVEL FLT	1500/420	LLNAV	WINDBLAST, LACK OF VIS CAUSED WSO TO EJECT AIRCREW. PILOT INJURED DURING CAPSULE IMPACT.
F111	SL/NO R	–	136	LOW LEVEL FLT	1000/480	LLNAV	PILOT SYSTEM & RADOME DESTROYED
F111	SL/NO R	11000	8	RANGE	500/480	GND ATK.	SWALLOW
F111	SL/NO R	11000	12	RANGE	1500/250	GND ATK.	
F111	SL/NO R	11000	12	LOW LEVEL FLT	1000/480	LLNAV	
F111	SL/NO R	–	12	RANGE	500/480	GND ATK.	NIGHT
F111	SL/NO R	16AAC	8	CLIMB	6-7000/350	–	
F111	SL/NO	11000	12	RANGE	–	–	NIGHT
F111	DESTROYED/ MAJOR	–	–	RANGE	400/480	GND ATK.	NIGHT. BLAST, DEBRIS MADE IT IMPOSSIBLE TO DETERMINE ATTITUDE PILOT INJURED BACK (WSO EJECTED AIRCREW)
F111	SL/NO	16000	–	RANGE	200/480	GND ATK.	SMALL BIRD

Table 4

EXPLANATION OF COLUMN HEADING TERMS FOR TABLE 3

TERM	DEFINITION
A/C TYPE	ROLE OF EACH TYPE CAN BE DETERMINED BY LETTER DESIGNATION. A – ATTACK (BASICALLY AIR-TO-GROUND) B – BOMBER F – FIGHTER C – CARGO (KC-TANKER) T – TRAINER "R" PREFIX DESIGNATES A RECONNAISSANCE MODEL (e.q. RF-4)
DAMAGE/INJURY	NO – NONE SL – SLIGHT (R) MEANS REPLACEMENT OF WINDSCREEN, CANOPY, OR WINDOW WAS REQUIRED
WUC	WORK UNIT CODE – CALLS OUT COMPONENT WORKED ON AND TYPE OF MAINTENANCE PERFORMED. CAN BE DETERMINED THROUGH A STANDARD WUC LISTING AVAILABLE FROM USAF
HRS. REP.	MAX HOURS TO REPAIR – MAY INCLUDE WORK SPENT ON OTHER COMPONENTS OF AIRCRAFT DAMAGED IN INCIDENT (e.q. ENGINES)
OPS PHASE	WHAT THE AIRCRAFT WAS DOING AT THE TIME OF THE INCIDENT (e.q. T.O. – TAKEOFF, CLIMB, CRUISE, ETC)
ALT/AS	ALTITUDE (ABOVE GROUND LEVEL)/AIRSPEED (INDICATED) IN KNOTS
TYPE MISSION	REASON FOR FLIGHT
OTHER DISC	OTHER INFORMATION OF INTEREST SUCH AS TYPE OF BIRD, NO. OF BIRDS, WHETHER IT WAS A NIGHT FLIGHT, ETC.

```
84-34-79-423              F111A                        INCIDENT
    DAMG CLAS - SLIGHT              INJ CLAS - NONE
    TYPE - OTHER COLLISIONS
    COND -
    PHASEOPR - LOW LEVEL FLIGHT
    BASIC - BIRD STRIKE
    BASIC - CRACKED
      W-U-C    - 16AAC          HRREPAIR- 00008
SCRIPTION  F-111A.  16 SEP 75, 1148 PDT, 350 DEGREES, 40 NM FROM
           NELLIS AFB, NV.  LEFT WINDSHIELD CRAZED DUE TO BIRDSTRIKE.
           TEN MINUTES AFTER TAKEOFF, A BIRD STRUCK THE LEFT
           WINDSHIELD.  BIRD IMPACTED WINDSHIELD ON CENTER LINE ONE
           INCH BELOW UPPER CANOPY BOW.  AIRCREW WAS CLIMBING THROUGH
           10,500 FEET MSL, 6 TO 7000 FEET ABOVE GROUND LEVEL, 350
           KIAS.  DUE TO AIRCRAFT COMMANDER'S REDUCED VISIBILITY, A
           WING APPROACH TO SHORT FINAL WAS FLOWN AND LANDING WAS
           UNEVENTFUL.  AIRCREW HAD VISORS DOWN AT TIME OF BIRDSTRIKE.
           AIRCRAFT NOT MODIFIED WITH IMPROVED BIRD RESISTANT
           WINDSHIELD.
           ENVIRONMENTAL FACTOR, LEFT WINDSCREEN CRAZED BY BIRDSTRIKE.
```

*Figure 9 Sample Computer Printout of Canopy Incident Data**

The data of Table 3 provides the essential information of reported incidents and accidents, how and when they occurred, and required repair/replacement, if any, and thus serves to establish the threat taxonomy and operational descriptions discussed in Section 4. Summarization of the threat data as contained in Table 3 in the format shown in Table 5 provides both an overview of the threat statistics for the birdstrike problem to the F-111 and the basis for establishing new technology goals or requirements to alleviate the problem. Note that Table 5 also contains birdstrike data developed for the F-4 over a comparable five-year period.

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* Reference 5

TABLE 5

F-111 AND F-4 BIRDSTRIKE THREAT STATISTICS

DESCRIPTOR	F-111 A/C	F-4 A/C
Time Frame	5 years	5 years
Number of Incidents	34	21
Number of A/C Lost	3	0
Number of Pilots Injured	2	0
Number of Canopies Replaced	16	14
Maintenance Manhours	750	1550
Mission Type (Principal)	NAV/GND ATK	NAV/GND ATK
Operational Phase (Principal)	LOW LEVEL FLT	LOW LEVEL FLT
Maximum Incident Altitude	6-7000 ft	7000 ft
Nominal Flight Altitude	1380 ft	1270 ft
Nominal Flight Speed	433 mph	420 mph
Minimum Flight Speed	250 mph	200 mph

<u>Threat Index Computation</u>

The threat index is designed to permit the priority ranking of all threats on the basis of severity, frequency, and incurred costs. On an independent basis (i.e., when derived for a single threat type as in the present case) the index is used to determine the significance of the threat for different types of air-flight vehicles and to rank or compare the relative improvement of proposed technology solutions to the given threat with existing conditions. The following exercise develops the threat indices for the subject birdstrike threat to the F-111 and F-4 aircrafts. In later paragraphs, the threat index for the F-111 is recalculated for a proposed technology candidate to alleviate the threat problem and then compared with the present index (for the F-111) to establish a relative improvement resulting from the technology change.

Major assumptions required for developing the threat indices for the F-111 and F-4 aircraft are listed in Table 6.

TABLE 6

MAJOR ASSUMPTIONS

DESCRIPTORS	F-111	F-4
Fleet Size - No. of Aircraft	340	1150
No. of Flying Hours/AC/Yr	300	300
Average Duration/Sortie	3 hours	2 hours
Replacement Cost of Existing Canopy	$30,000	$10,000
Repair Cost/Manhour	$30 (including minor parts)	$30 (including minor parts)
Cost of Major Injury	$25,000	$25,000
Aircraft Replacement Cost	$15,000,000	$3,000,000

The threat index is computed from the relations:

$$I_T = P_{(E/S)} \times C_E \times N_{F/I} \times C_s \qquad (1)$$

$$\text{and } P_{(E/S)} = N_E \left[\frac{1}{N_{F/I} \times \frac{N_H}{T_A} \times t} \right] \qquad (2)$$

where

I_T = Threat Index

$P_{(E/S)}$ = Probability of Engagement per Sortie

C_E = Average Cost per Engagement

$N_{F/I}$ = Number of Systems or Equipment in the Fleet or Inventory

C_s = Cost of System

N_E = Reported Number of Birdstrike Incidents in time t

N_H = Number of Flying Hours per Aircraft per Year

T_A = Average Flight Hours per Sortie

t = Time Frame of Interest (Years)

Using data from Tables 4 and 5, the probability of birdstrike engagement per sortie for the F-111 is computed as:

$$P_{E/S} = 34 \times \frac{1}{340 \times \frac{300}{3} \times 5} = .0002 \quad \text{(From Equation 2)}$$

The contributing and total repair/replacement costs for the five-year period are obtained by applying the cost factors of Table 6 to the incident data of Table 5. For example:

Item	No.	Unit Cost	Subtotal
Aircraft Replacement Costs	3	$15,000,000	$45,000,000
Pilot Injury Costs	2	$ 25,000	$ 50,000
Replacement Canopy Costs	16	$ 30,000	$ 480,000
Maintenance Costs	750 hrs	$ 30/MH	$ 22,500
		Total:	$45,552,500

The average cost per birdstrike incident is $1,340,000 with an annual average cost to the Air Force of $9,111,000. Using the above calculated values, the normalized* threat index for the F-111 case becomes:

$$I_T = .0002 \times \$1.34 \times \$15 \times 340 = 1.367 \quad \text{(From Equation 1)}$$

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*Normalization implies that dollar values in the threat index are expressed in millions of dollars.

Table 7 presents, for comparison purposes, selective data derived for both the F-111 and F-4 aircraft. From the table, the threat index for the F-111 (i.e., I_T = 1.367) is noted to be significantly greater than that derived for the F-4 (i.e., I_T = .000728). The F-111 birdstrike/windscreen problem therefore would be ordered or ranked well above that for the F-4. One should recognize that similar threat indices, derived for a multitude of threat types and then combined and arranged in descending order establishes the priority ranking of threats as intended for the threat identification and ranking portion of the TES methodology. Further, that threat data analogous to that of Table 5 for the birdstrike threat, if developed for each threat type would serve as an aid in the definition of new technology goals or requirements. For the present threat problem, the technology goal might be specified as:

> "An F-111 windscreen design improvement is required that will be capable of withstanding, without penetration at any given location, the impact of a four (4) pound bird when the aircraft is at maximum Mach number of 0.85 at or below 8000 ft under standard hot and cold air conditions as noted in MIL-STD-210B. All other technical requirements for the existing canopy must be applicable to an improved design."

TABLE 7

COMPARISON OF F-111 and F-4 DATA

DESCRIPTOR	F-111 A/C	F-4 A/C
$P_{(E/S)}$	.0002	.000024
I_T	1.367	.000728
No. Incidents	34	21
Avg. Cost/Incident	$1,340,000	$ 8,800
Avg. Annual Cost	$9,111,000	$37,300

Evaluation of a New Technology Program

Publication of the threat listing and statistics and new technology goals will result in the receipt of candidate technology programs to alleviate identified threat problems. For the present case involving the F-111 windscreen, proponents would likely recommend the development of an improved plastic design indicating its advantages, anticipated technical characteristics, and economic factors. Technical and cost data provided by the proponent in general will favor pursuit of the technology program with minimum emphasis on the identification of subtle problems and/or risks inherent to the new design.

The role of the evaluation team of analysts under the improvement analysis portion of the methodology is to establish the credibility of each proposed design. The evaluation process would likely address the comparison of the various technical and economic aspects of the proposed plastic design with corresponding technical and economic considerations for the present glass canopy. Noting the existence of a Bird Impact Model* as well as other models developed for use with aircraft canopies, the evaluation team could exercise the model to both verify information provided by a proponent and establish performance limits by varying key parameters.

Assuming that the improvement analysis establishes technical feasibility for a particular design and that the design provides for bird impact resistance commensurate with the technology goal, technical changes between the proposed plastic and existing glass canopies which influence the performance parameters of the aircraft would be identified; for example, changes in weight, shape, signature characteristics such as RF and IR cross sections, optical properties, etc. These changes would then represent input data for the effectiveness/survivability evaluation module.

The extent of analysis conducted under the effectiveness/survivability evaluation would depend on the identified changes in technical performance parameters for the F-111 which are directly attributed to the proposed new windscreen. Minimal variations in all performance parameters would likely indicate

*AFFDL Technical Report TR-77-99

deletion of the effectiveness evaluation. Improved windscreen resistance to birdstrikes may indicate reduced vulnerability to weapon system fragmentation effects and thereby increase aircraft combat survivability. The improvement in combat survivability (if any) would be assessed by exercising the BETA model for both the unimproved and improved F-111 airframe with the improvement reflected as a decrease in vulnerable area. For the case of an improved windscreen recognized to provide reduced vulnerability to weapon system fragmentation effects with minimal weight and shape changes, and exhibiting comparable optical and signature characteristics with the original glass canopy, no attempt would be made to examine the improved aircraft for mission effectiveness.

The cost analysis in this example is predicated on the assumption that implementation will culminate in the production of a plastic canopy which will prevent aircraft losses entirely as a result of bird impacts but will require the same number of canopy replacements as was the case for the present glass canopy. The cost of the new canopy is assessed at $200,000. The application of this cost and replacement assumption to the data in Table 5 yields a total anticipated repair/replacement cost of approximately $3,824,000 or $112,000 per incident; that is:

19 canopy replacements @ $200,000 ea.	$3,800,000
10 hrs/replacement @ $30/MH for 3 additional canopies	900
750 hrs maintenance @ $30/MH	22,500
Total:	$3,823,400

Thus, the annual repair/replacement cost for the new technology canopy is $765,000 (i.e., $3,824,000/5 yr).

Assuming that the life span of the F-111 fleet following the availability of the new canopy is 10 years, the total cost of the new program is as follows:

RDT&E	$10,000,000	
Acquisition & Installation	68,000,000	(340 A/C x $200,000)
10 yr Repair/Replacement	7,650,000	(10 yr x $765,000/yr)
Total:	$85,650,000	

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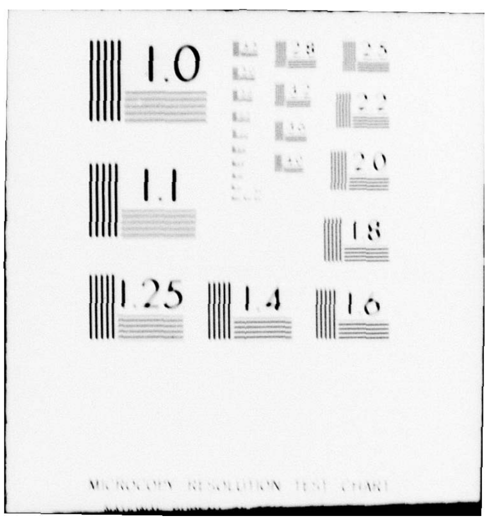
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MICROCOPY RESOLUTION TEST CHART

The corresponding cost incurred by retaining the extant canopy is $91,110,000 (10 yrs x $9,111,100/yr).

The new technology program was assumed to provide a significant improvement; i.e., it eliminated the loss of aircraft due to birdstrike. Of the five-year repair/replacement cost of $45,553,000 incurred with the present canopy, $45,000,000 was accounted for by the loss of three aircraft.

The total cost of the new program is approximately the same as the cost that would be incurred by keeping the current glass canopy; $86 million vs $91 million such that no appreciable savings are realized. This, in fact, is what should be expected in connection with the implementation of practically all safety programs. Incidents or accidents, i.e., engagement probabilities of noncombat threats, are relatively rare events. In order to alleviate or negate these threats, however, modifications or additions required by the new technology program must be made in <u>all</u> air vehicles in the fleet. Note that the RDT&E, acquisition and installation costs of the new technology program amount to $78 million which represents 85% of the cost which would have been incurred with the extant technology. It must be expected that the cost of alleviating many noncombat threats will exceed the value of the benefits obtained. The criterion that the benefit/cost ratio must be >1 cannot always be applied to the evaluation of new technology programs which address noncombat threats.

Additional information regarding the benefit gained by implementing the new technology program, however, is obtained by comparing the threat index computed with the present technology vs the threat index with the new technology in place.

I_T with the new technology is:

$$0.0002 \times .112 \times 15.23 \times 340 = 0.116$$

This represents a 92 percent reduction in the threat index.

<u>Final Discussion</u>

The threat indices of noncombat and combat threats will be computed in the same manner. Direct comparison within each category of threats will, therefore, be possible. Once threat indices have been calculated for both

present technologies and new technology programs, a decision rule can be formulated for ranking the technology programs. For example, in the case of noncombat threats this could be based on the relative improvement achieved, attainment of a given index value, or the cost per unit of I_T improvement, i.e., $\frac{I_{T(OT)} - I_{T(NT)}}{C_{(NT)}}$ where $I_{T(OT)}$ and $I_{T(NT)}$ represent the threat indices of the old and new technologies, respectively, and $C_{(NT)}$ is the cost of implementing the new technology.

The ranking of technology programs must in the limit be recognized as a subjective decision process; that is, one that has assimulated the results of available data and numerical computations (e.g., calculated change in threat indicies), as well as considerations of a technology impact on:

- Achievable attrition reduction
- Long-range reliability and maintenance
- Benefit cost ratio, potential cost savings, break-even point
- Air-vehicle performance characteristics and effectiveness.

These latter considerations represent the various types of outputs one can expect to derive from the tradeoff analysis portion of the TES methodology.

SECTION VI

PROPOSED IMPLEMENTATION PLAN

The current program had as its principal objective, the development and qualitative assessment of a system architecture for the identification, evaluation and ranking of threats and related candidate technology programs. The selected approach has been noted to be primarily procedural in nature with reduced emphasis on the extensive use of computer models and/or simulations. The procedural aspects of the methodology emphasize the application of an ordered sequence of steps (or events) by which a team of analysts can establish threat rankings, the potential worth of candidate technologies and formulation of cost-benefit decisions for ranking of the technologies.

The organization of the TES methodology is such that it permits the derivation of specific (and useful) outputs at intermediate points in the methodology. For example, major information and decision outputs would be available (1) with the publication of the identification and ranking of threats, (2) following the preliminary evaluation of proposed technology programs, and (3) following the detailed cost/effectiveness evaluations. The recommended approach for implementation of the methodology, therefore, is that of a sequential three-phase program to develop the organizational and analysis procedures, data requirements and computer models (as appropriate for the cost/effectiveness and tradeoff evaluations) for use under each of the major steps and in their order of occurence as shown in Figure 1. This approach permits for an efficient and gradual build-up of the methodology; exercising of specific elements of the methodology prior to full implementation and, in the event that full implementation is not realized, the completed portions (i.e., the threat identification and ranking and/or the preliminary evaluation/screening procedures) would still be of significant value to the Air Force.

A proposed schedule, phasing and cost estimates for the implementation program are given in Table 8.

TABLE 8

IMPLEMENTATION PLAN SCHEDULE & FUNDING ESTIMATES

	TIME FROM PHASE 1 START (SIX MONTH INTERVALS				ESTIMATED FUNDING LEVEL
	1	2	3	4	
PHASE 1					
Threat Identification & Ranking • Noncombat					$90K
PHASE 1A					
Threat Identification & Ranking • Combat					$60K
PHASE 2					
Preliminary Technology Assessment Procedures					$25K
PHASE 3					
Interim Initial Performance/Cost Effectiveness Analyses & Models Development					$125K
Demonstration of Interim Analyses & Models					$40K
REPORTING (Interim and Final)					

Phase I - Noncombat Threat Derivation

This phase encompasses the identification and evaluation of the noncombat threat. Threat identification and evaluation is to be performed in accordance with the Implementation Plan guidelines established in Section 4.2.1.4.

Because this portion of the methodology will require access to large quantities of potentially sensitive accident and contractor performance data, time lags to establish need-to-know and need to access are anticipated. To a certain extent, it may also be time consuming to locate the pertinent sources of economic data. (Economic data in the form of maintenance parts and labor expenses are treated as a threat of equal status with accident inducing threats. Having access to the required data, threat indices will be developed by individual threat (birdstrikes vs. F-111 windscreens) as well as larger groupings (birdstrikes for all aircraft, windscreen problems for F-111, windscreens in general, etc.).

Publication of the results and documentation of the methodology in two AFFDL technical reports will complete the effort.

Phase IA - Combat Threats

Phase IA may be executed either in parallel to, or in sequence with, Phase I. The purpose of this phase is to develop the combat threat. The combat threat consists of an identification of the hostile threat systems which might attack aircraft for the foreseeable future. The threat must be treated from two aspects. In the more fundamental aspect, the threat is identified in terms of the lethality and damage mechanism. That is, overpressure crushing, structural damage, fuel fire and explosion, pilot incapacitation, and lethality and related phenomena. On the systems level, these factors are to be related specifically to threat systems, SAMs, AAA, AAM, HEL, etc.

Finally, a list of missions must be developed and described. For each of the missions, probabilities of encounter with each of the threats must be established. Threat indices are then constructed for the threats as systems and as damage mechanisms. The extension of the threat description to the damage mechanism is needed so that research aimed at performance which reduces

the threat system lethality as well as hardening measures which act on the vulnerability mechanisms will be proposed as research programs.

The identification and analysis of combat threats must be derived largely from analysis and simulations rather than historical data. It is anticipated that combat threats will be considerably fewer in number, require less data collection but more analysis than noncombat threats. It should also be noted that the analyses and simulations employed for the purpose of identifying and ascertaining the frequency of encounter and severity of the combat threats will be applicable in the evaluation of the new technology program candidates.

Phase II - Technology Programs Screening

The purpose of Phase II is to establish a preliminary screening and evaluation capability at AFFDL. This activity is envisioned as a management consulting effort to establish the administration procedures to support forms and formats for evaluation and to establish within the AFFDL staff the proper spirit of evaluation.

As with the overall methodology, the goals of this phase of the procedure are to stimulate and facilitate the submission and approval of programs and to provide justification of the selected program to higher headquarters. Limited consultation on the publication portion of the methodology is also contemplated as a part of this phase.

Phase III - Evaluation Methodology Development

The purpose of this phase of the methodology development is to implement the methodology discussed in Section 4. In addition, the requisite cost and cost/effectiveness models described in Sections 4.2.5 and 4.2.6 will be developed. A limited exercise of the methodology will be performed as noted in Section 4.2.7. The effectiveness model will undoubtedly be revised in subsequent periods but the extent and depth of such revision cannot reasonably be anticipated at this time. A separate computer model and exercise portion is identified.

SECTION VII
CONCLUSIONS

The objective of the Total Environmental Survivability (TES) methodology program was to provide Air Force planners with the capability to evaluate the relative importance of (1) threats on technologies, and (2) technologies on air-flight vehicle non-nuclear survivability in the total environment. This capability was to be associated with mission effectiveness and life cycle cost analyses to provide a ranking of the relative payoffs of the alternative technologies. The following conclusions represent the principle findings of the study effort to formulate the desired TES methodology.

1. A procedure can be developed which will rank noncombat and hostile threats which affect the operational readiness and use of air-flight vehicles.

2. Although essentially the same methodology can be used to determine noncombat and hostile threat rankings, the rankings should not be combined. This conclusion is based on the realization that combat threats account for the vast majority of air-vehicle losses with peacetime and noncombat losses <u>generally</u> falling into the category of occasional or rare events on a comparative basis.

3. Threat descriptors can be developed to the point whereby technologies which have potential to counter the threats, either in total or in part, can be identified.

4. The impact of new technologies on air-flight vehicle combat survivability can generally be determined using extant analytical or simulation models of identfied threats. To maintain credibility and usefulness, the existing survivability methodologies are being continuously upgraded to reflect improvements in threat systems while new methodologies must be developed to address advanced threats (e.g., laser weapons, advanced SAMs, etc.)

5. The impact of new technologies on air-flight vehicle mission effectiveness (distinct from survivability) can only be measured for technologies which result in significant changes in the air-flight vehicles technical and performance characteristics. Mission effectiveness models generally are not sufficiently sensitive to provide credible results for small variations in inputs.

6. Because of the variety of air-flight vehicles, threats and technology programs which must be considered, the derivation of a credible single measure of merit which combines survivability, cost and effectiveness considerations does not appear feasible.

7. The recommended procedure for ranking threats and technologies and for determining the impact of new technolgoes on air-flight vehicles' costs, survivability, technical and performance characteristics, can provide new and useful inputs to the new technology investment decision process.

SECTION VIII

REFERENCES

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